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PARTICULATE SCIENCE TEAM  
REPORT

ON

ACTIVITIES CONDUCTED DURING THE  
DEFINITION PHASE  
OF THE

OUTER PLANETS MISSIONS PROGRAM

**CASE FILE  
COPY**

FINAL REPORT  
TO

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ON

GRANT NUMBER NASA-NGR-39-004-042

DREXEL UNIVERSITY  
PHILADELPHIA, PENNSYLVANIA

OCTOBER 1972

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## I. INTRODUCTION

This report of the Meteoroid Science Team for the Definition Phase of the Outer Planets Missions describes the activities of the team during the definition phase study from April 1971 through September 1972. These activities were carried out under grant number NASA-NGR-39-004-042 from the National Aeronautics and Space Administration to Drexel University. The text below gives a chronologic history of the team's activities through the various changes in the program direction. A number of contributory studies were carried out by various members of the team and their organizations. To maintain the text continuity and for ease of reading the results of these studies are frequently summarized in the text and presented in condensed form or in their entirety in the appendices. For completeness, minutes of the team meetings are also appended.

## II. METEOROID SCIENCE TEAM MEMBERSHIP

The official membership of the Meteoroid Science Team is presented below. The affiliation and address of each of the team members is also given. A list of the organizational responsibilities of each of the team members follows.

### A. Team Members, Affiliations and Addresses

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B. Team Organization

Hugo Fechtig	Particle composition. Small particle detection.
Joseph Friichtenicht	Particle composition. Small particle detection.
Bertil-Anders Lindblad	Orbital determinations. Small particle detection.
Alan W. Peterson	Photometry of extended sources.
Robert G. Roosen	Photometry of extended sources.
Robert K. Soberman*	Large particle detection. Orbital determinations.
Jerry L. Weinberg	Photometry of extended sources.
Gerard L. Zomber	Experiment design.

\*Team Leader

C. Changes in Team Membership

In the proposal for the second phase of the Outer Planet Missions Program, some changes were made in the team organization. These changes were made in keeping with the requirements for the implementation of the proposed experiment on the Mariner, Jupiter, Saturn 1977 Missions. Mr. G. L. Zomber was deleted as a team member but would continue as Principal Engineer for the investigation. Since his duties were to be primarily in the areas of hardware implementation and program management, it was considered inappropriate for him to be carried as a science team member. Dr. Eberhard Grün of the Max Planck Institut für Kernphysik, was added as a team member for the mass spectrometry portion of the combined investigation. Dr. Charles F. Lillie of the Laboratory for Atmospheric and Space Physics of the University of Colorado, was added as a team member for the portion of the investigation dealing with photometry and polarimetry. Dr. Frederick B. House of Drexel University was added as a team member for the optical particle sensing portion of the combined investigation. The addresses of these individuals are listed below.

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### III. COMBINED ZODIACAL EXPERIMENT FOR THE GRAND TOUR MISSIONS OF THE OUTER PLANETS

The originally proposed investigation for the Outer Planets Missions Program was a combined investigation that included photometry and polarimetry of extended sources, photometric detection of particulates and detection and analysis of micro-particles by various impact phenomena. These phenomena included impact ionization, impact light flash and acoustic waves in the target. The instrumentation was to have been combined in a set of four telescopes which were stationary with respect to the spacecraft. The concept for this Combined Zodiacal Experiment was discussed in a paper presented at the 17th Annual Meeting of the American Astronomical Society (see Appendix A).

#### A. Particle Composition Measurements

Quite soon after selection, it became apparent that composition measurements of particulates were important to the scientific objectives of the investigation. Consequently, studies were undertaken to determine the best way of implementing such compositional measurements into the instrumentation for the investigation. Two versions of time of flight impact mass spectrometers were known to exist. One was the Cosmic Dust Analyzer, developed at TRW Systems, Incorporated, and the other an instrument being built for Helios Spacecraft under the direction of the Max Planck Institut für Kernphysik in Heidelberg.

A number of differences existed between the two mass spectrometers primarily in target configuration, grid configuration and voltages, ion collectors and on-board data handling techniques. The two organizations (i. e. TRW Systems, Inc. and Max Planck Institut für Kernphysik) undertook an effort to design a single optimum system which could be most easily incorporated within the constraints of an outer planet missions spacecraft. The two groups first approached the problem separately with the intent of combining the best features of both studies into a single final design. The problems to be addressed included the following:

1. Analysis and Tradeoff Studies of the Geometric Constraints

Since both the optical detection system and the composition analyzer could assume several configurations, the purpose of this subtask was to determine which compatible configuration would yield maximum data for both experiments. Within the selected configuration the optimum placement, size, and shape of the impact target would be determined.

2. Target Material Testing

In order to obtain maximum ionization and proper calibration for the time-of-flight mass analysis, a suitable target material must be selected and tested. Since this target may also form part of the optical detection system, it must be selected within the constraints imposed by the telescope design.

3. Determination of Accelerating Voltage and Grid Configuration

The objective here was to minimize the accelerating voltage (giving a longer ion time-of-flight) consistent with holding the resolution deterioration (due to thermal spreading of the ion pulses) to a minimum; this would be determined experimentally using Van de Graaff hypervelocity particle accelerators. Effects of accelerator grid location and mesh size, electric field at the target, and total accelerating voltage would be analyzed and optimized.

4. Specification of an Initial Data Storage System

Since the total ionization pulse is short and one needs to examine differences in arrival time which will be of the order of microseconds, an initial data storage and analysis system must be defined, consistent with the overall constraints. The results of tasks A, B, and C would determine the inherent resolution of the composition analyzer. The initial data storage system must have a sufficiently wide bandwidth (i. e. rapid response time) to store the ionization signal without further degrading the resolution. Electronics capable of meeting this requirement and operating within the system and environmental constraints must be defined.

- B. Additional Particle and Photometry Measurements

In addition a number of efforts associated with the optical detection experiments (particulate impact, remote particulate photometry, and extended source photometry), were undertaken to determine the optimum integration of the experiments into a single combined configuration. These studies included the tasks described below:

1. Impact Target Investigation

Early plans called for the impact target to be part of an optical telescope. Therefore, an investigation into target materials was required, which would provide the optimum telescope and impact surface configuration. Target materials had

to be compatible with the thermal as well as the radiation environment expected during the mission. The feasibility of using the primary mirror of the optical telescope as the target was already being investigated. The stringent weight restrictions of the Thermo-electric Outer Planets Spacecraft (TOPS) formed the major design constraint. Early samples of lightweight target designs were to be provided to both TRW and the Max Planck Institut for micrometeoroid flash and composition testing in their hypervelocity facilities.

## 2. Key Electronic Component Environmental Testing

The environmental conditions to be encountered by the instruments on the TOPS vehicle (particularly in the vicinity of Jupiter) required that sensors and key components be carefully selected and tested. Under this task, photomultiplier tubes would be purchased, tested, and provided to the Jet Propulsion Laboratory for environmental testing and evaluation. A final selection would then be made of a photomultiplier which would not degrade with time and whose end window would not darken when heavily irradiated. Furthermore, a breadboard consisting of key logic assemblies and a power supply, was to be built of radiation hardened low power components intended for flight use. These would also be submitted to JPL for irradiation and subsequently evaluated.

## 3. Photometry of Extended Sources

Parametric studies were required in the design of the combined sensor to ensure that optimum data would be obtained on the zodiacal light, galactic light, and cosmic light (integrated light from extra-galactic sources). Measurement of brightness and polarization in several colors should also provide information on the refractive index and, therefore, on the chemical composition of the particles.

Among the required specifications were: aperture size, method for determining polarization, filter wave length and bandwidth, location, frequency and scan or spin rate for observation, optimum field of view, and in-flight calibration methods. Design concepts from ground, Skylab, and Pioneer zodiacal light experiments were expected to contribute to these specifications.

## 4. Overall System and Mechanical Integration

In this task the requirements of all of the experiments were to be integrated into a single design which would optimize the data yield for the remote optical particle detection, the photometric measurements, and the various impact sensors. The system design criteria included minimum weight, volume, and power consumption, with maximum reliability.

## 5. Electronics Integration

In this task, the electronic processing requirements of the experiments were to be integrated into a single conceptual electronic design, utilizing minimum weight and power while ensuring survival for the ten year Outer Planets Missions.

Trade-off studies were to be performed on data yield and total weight and power consumption for the combined electronics package.

#### IV. STUDY RESULTS

##### A. Configuration Design

Early in the effort it became apparent that the initial instrument configuration presented a problem for optimum photometric measurement and impact measurements. The problem was in obtaining a sufficiently large acceptance angle for particle impacts while constraining the stray light for the photometric measurements. The initial configuration (i. e. using the telescope primary mirror as the impact surface), gave too small an acceptance angle for particle impact. Consequently, configuration studies were carried out in an attempt to obtain a large acceptance angle for particle impact while limiting stray light from various spacecraft structures. The result of these studies was a configuration which used a honeycomb structure ahead of the telescope for the particle impact target and as a stray light suppressor. It was found that such a honeycomb panel could be placed in front of a telescope without appreciably reducing the amount of light received from a narrow telescope field of view. A report on the optical transmission of such a structure and its effectiveness as a particle impact surface was prepared and is presented in Appendix B.

##### B. Target Investigation

As a consequence of the above cited study, the required properties of the impact target changed drastically. It no longer needed to be a good optical reflecting surface. On the contrary, for incorporation at the opening of the telescope, the honeycomb material was now required to be a poor reflecting surface so that a minimum of light from outside the field of view was scattered into the telescopes. Consequently, new target materials were investigated. One still required that the target material yield, on impact, a measurable light flash, a detectable acoustic signal, and a sufficient number of ions and electrons from the plasma such that these phenomena could be measured. Materials such as gold which were originally under consideration gave way to beryllium, tungsten and tantalum. These latter materials gave indications of the requisite properties. The results of the target material investigations are included in the various reports appended. Tungsten proved to be the best material but the weight of a tungsten honeycomb panel presented a mechanical problem.

##### C. Composition Analyzer

Both groups (TRW Systems, Inc. and Max Planck Institut für Kernphysik) that were investigating the composition analysis instrumentation continued to work on designs which would minimize overall sensor length and the voltage levels required. These studies were directed toward obtaining minimum weight and power such that the instrumentation could be accommodated on the Thermoelectric Outer Planet Spacecraft as it was evolving. The results of their early studies are presented in Appendices C and D.

#### D. Light Weight Optics

The original Grand Tour particle investigation concept was to have made measurements to heliocentric distances of 30 to 40 astronomical units. For sensing particles by reflected sunlight at those distances, large aperture telescopes were required. To minimize the telescope weight, a study was undertaken into techniques of fabricating large aperture mirrors of light-weight design which would be thermally stable in the environment expected. The results of this study, which was only partially completed (due to the redirection of the project from the Grand Tour to Jupiter/Saturn Missions) is presented in Appendix E. While the results are encouraging for future missions to large heliocentric distances, fiscal constraints dictated that MJS '77 mirror fabrication techniques follow those already developed for the Pioneer Missions to Jupiter. With certain improvements in efficiency which were demonstrated during this OPM definition phase study, mirrors almost identical in design and size to those used for the Asteroid/Meteoroid Detector on Pioneer 10 and G could be adapted for use to heliocentric distances of 10 au and somewhat beyond. A major improvement in light gathering efficiency (which was demonstrated during this definition phase) was that of overcoating the optical surface (originally fabricated of gold) with a second material that had a better reflective spectral response than gold. As a test, a mirror was prepared using the fabrication technique developed for Pioneer and then overcoated with aluminum and a protective silicon monoxide layer. The optical surface was shown to have improved the reflectivity for a solar spectrum of incident light from 69% to 96%. Since the Cassegrain telescope design uses two reflections (i. e. from a primary and a secondary mirror) the improved efficiency of this coating would be approximately a factor of two. The mirror so fabricated was subjected to thermal, vacuum, and proton radiation susceptibility testing equivalent to the environment expected during the Grand Tour Missions. No degradation in optical or mechanical properties was noted.

#### E. Circuit Design and Component Testing

As discussed above, the Grand Tour Missions were expected to receive extensive radiation exposure during close approach to Jupiter. One of the missions was to have passed within 0.1 planetary radii of that planet's surface. Prior testing of the Asteroid/Meteoroid Detector under the Pioneer program had shown the early COMOS logic which was being used extensively in the instrument, to reduce weight and power, would not survive the predicted radiation environment expected during such an encounter. Consequently, an effort was initiated to select components and design low power radiation resistant circuitry of high reliability which could survive the anticipated environment. Under this task, a design, utilizing dielectrically isolated low power TTL logic was completed for the optical particle detector. Key circuits were breadboarded for irradiation tests (see Figures 1 and 2). These breadboards were sent to JPL for the irradiation. Prior to the cancellation of the Grand Tour Missions, these circuit boards were exposed to proton fluences greater than  $10^{11} \text{ cm}^{-2}$ . Planned neutron and gamma ray exposures were never carried out. The proton exposure was documented in JPL Inter-Office Memorandum dated 7 February 1972, by R. H. Parker, subject: "January 11 - 12 Proton Test at UCLA". After proton irradiation, the breadboards were returned for evaluation. No measurable degeneration was found in any of the irradiated circuits.

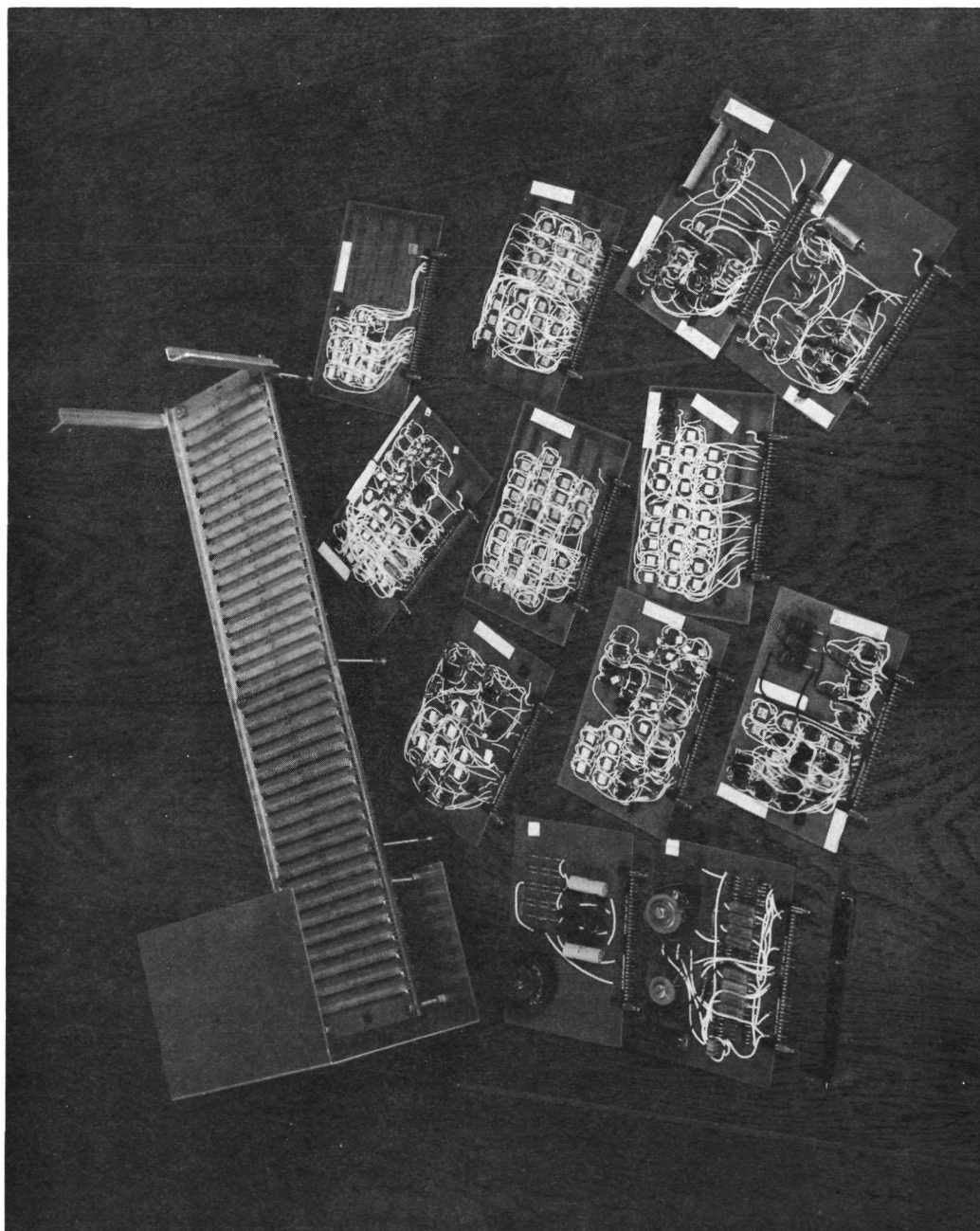


Fig. 1. Key Circuits Breadboarded for Radiation Susceptibility Testing.



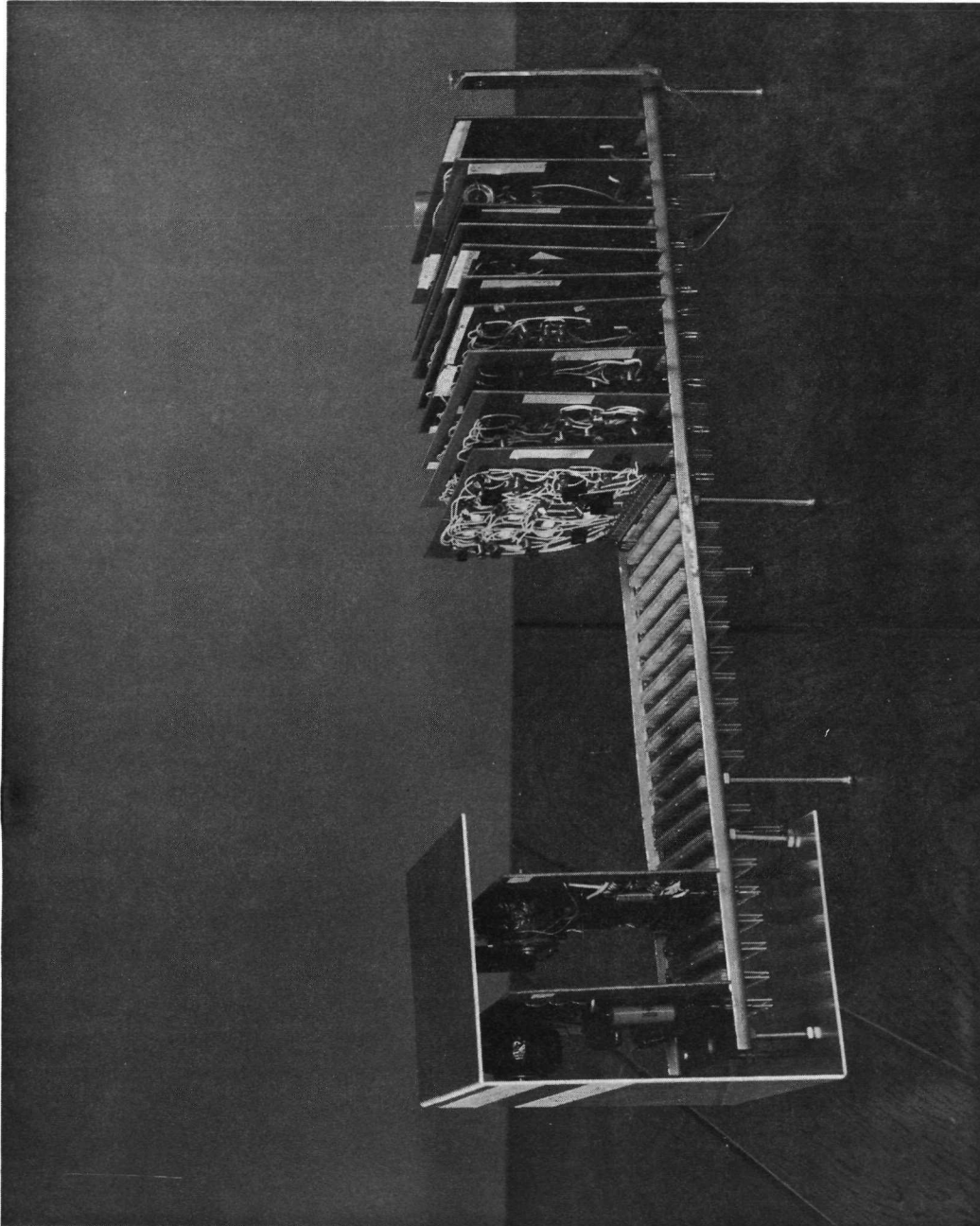


Fig. 2. Breadboards in Fixture for Irradiation Tests.

Two ITT photomultiplier tubes with S-20 photocathodes deposited on nondarkening end windows (Schott Glass type GG275g), were purchased and sent to JPL for irradiation. These also received only the proton fluence prior to termination of the test program. Upon return, these photomultiplier tubes were retested. While no darkening was found in either the end windows or the glass envelopes, appreciable gain and anode sensitivity degradation was found. A report treating this tube evaluation is presented in Appendix F. It was concluded that these particular tubes were unsuited for use in a close Jovian encounter mission. Investigations by another team involved in the Outer Planets Missions Definition Phase showed that at least one photomultiplier tube could be expected to survive such a radiation environment without appreciable degradation\*. Consequently, it was concluded that for any future missions in which close Jovian encounter (<R<sub>J</sub>) would be anticipated, additional effort would be required to identify the optimum photomultiplier to be used.

#### F. Impact Flash Studies

An extensive investigation of the impact flash phenomenon was undertaken as part of this definition phase study. The parametric dependence of the impact light flash on target material as well as particle composition, mass and velocity were of interest. The results of this investigation were incorporated into a master's dissertation by G. Eichhorn of the Max Planck Institut für Kernphysik. A summary of this work is presented in Appendix G. This study proved the feasibility of performing such impact light flash measurements on impacting microparticles and yielded the design parameters for the instrumentation needed to perform such measurements in coincidence with measurements of other microparticle impact manifestations.

#### G. Photometry and Polarimetry of Extended Sources.

After individual study and deliberation, the team members responsible for the photopolarimetry met and drew up a list of specifications. These instrumental and spacecraft maneuver specifications were (in the opinion of these team members) the minimum required to meet the science objectives of polarimetry and photometry of extended sources on the Grand Tour Missions (see Section V). These specifications are reproduced below:

1. The system should be capable of measurement in four colors with approximately a 100 Å bandpass. The four colors should be a) near-UV, b) blue, c) 5300Å, and d) red. The detectors must be photomultiplier tubes and must use pulse counting techniques.

2. The system should be capable of measuring both, polarization and brightness (i. e., measure  $I_1$  and  $I_2$  separately).

\*Santa Barbara Research Center Internal Memorandum, from S. Pellicory to L. Watts, 29 August 1972 "Relative Spectral Response of RCA C31025J (GaAs) Multiplier Phototube After Proton Irradiation."

3. The signal-to-noise ratio should allow measurement of brightness down to  $10 S_{10}$  visual units.
4. The data recording system should have the capability of putting forth 10-bit words for  $I_1$  and  $I_2$  with a resolution of  $1 S_{10}$  visual unit.
5. The field-of-view of the system should be between four and six degrees.
6. Assuming a spin scan mode a) the instrument must be stray-light shielded, b) the main telemetry antenna must serve as a light shield, c) assuming a  $5^\circ$  field-of-view, there should be 24 steps,  $5^\circ$  apart, starting in the +Z direction and then going aft; there should be six calibration rotations.
7. An in-flight calibration source which is self-luminous should be mounted on the back of the shutter.
8. All four telescopes should be used for the measurement; stepped polarizers should allow scans in the two orthogonal polarization directions. This requires articulating the entire instrument.
9. With the assumptions given above, 30 rotations of the spacecraft are required.

## V. SUMMARY OF TEAM PLANNING FOR THE GRAND TOUR MISSIONS

At the behest of the Outer Planets Missions Project, a number of documents were prepared which treated investigation objectives and proposed instrumentation for the Grand Tour Missions. The conclusions are summarized in this section.

### A. Recommended Grand Tour Investigation Objectives

The overall objective is an extensive multiparameter study of the evolving and primordial particulate matter originating in, or transiting, the solar system and the dynamic interactions of this material with solar and planetary forces. The parameters to be studied include the velocity, size, mass, density, composition and spatial distribution of individual particles, and the photometric parameters of aggregates of particles.

1. Perform the first direct measurement of the spatial density and its heliocentric variation, mean velocity, mass and composition of interstellar grains transiting the solar system. The heliocentric flux variation expected to be dictated by interaction with the solar wind and solar electromagnetic radiation is of particular interest.
2. Study of the meteoroid concentration as a function of heliocentric distance:

a. Test the "Jupiter Barrier" theory which predicts a dramatic increase in particle concentration beyond the orbit of Jupiter. This is partly a special case of the "planetary sweeping effect" in which particle size is a major determinant. Consequently, a large range of particle sizes (from 0.1 micron to several kilometers) need to be studied. Similar but less pronounced examples are anticipated in crossing the orbits of all of the outer planets.

b. A search will be made beyond 5 au for predicted asteroid-like belts of particulate matter and for a possible comet source.

3. Investigate particle concentrations in orbit about the outer planets:

a. Specifically, it has been suggested that there exist particulate belts about Jupiter similar to those about Saturn.

b. Conduct a multiparameter in situ study of the known rings of Saturn and search for indicated fainter rings. It is specifically recommended that one of the Outer Planets Missions be targeted through Cassini's division of Saturn's rings to permit the proposed study of particulate concentration, size and composition.

4. Search for photometric enhancements arising from localized particulate concentrations at the libration points of the outer planets, especially Jupiter (e.g., in the region of the Trojans).

5. Make the first map of the absolute brightness of the milky way in the absence of scattered light from atmospheric and interplanetary sources.

6. Measure the intensity, polarization and color of diffuse galactic light (in an environment free of atmospheric and inner solar system scattering sources) to provide information on the interstellar grains that is independent of the extinction and polarization of starlight.

7. Take advantage of the absence of scattering sources to search for cosmic light to determine the distribution over the sky of integrated light from extragalactic light sources.

8. Since the main thrust of the Outer Planets Missions is studies beyond the orbit of Jupiter, the intensive measurements that will be made during transit of the asteroid belts are not detailed but include studies of the size distribution, mass, velocity, orbital parameters, composition and photometric properties of asteroids too small to be seen from the earth. An "asteroid alert" mode will be incorporated which will permit other on board instruments to be directed at asteroids in the meter to kilometer size range which might be expected to pass within several thousand kilometers of the vehicle.

## B. Grand Tour Missions Investigation

A combination of sensors similar to the Combined Zodiacal Experiment is required to meet all or even the major portion of the recommended investigation objectives. The measurements to be performed by the sensors are treated separately below.

### 1. Optical Particle Sensing

Sunlight in the visible portion of the spectrum reflected from a particle can be sensed and the transit times through separate optical fields-of-view measured. The limiting sensitivity should be +6 visual stellar magnitudes. The range to radius ratio for particle detection should be approximately  $5 \times 10^5$  at 1 au and decrease linearly with heliocentric distance. The minimum particle size detectable at 1 au should be approximately 20 microns increasing linearly with heliocentric distance. Particle brightness should be measurable to about 5% accuracy over a dynamic range of four orders of magnitude before saturation. The three velocity components of the particle are to be measured directly, two of these to an accuracy of approximately 3% and the third to an accuracy of approximately 15%.

### 2. Impact Ionization Analysis

Composition can be determined by drawing the ions produced at the particle impact point through a time-of-flight spectrometer. The dynamic range of this sensor should be from  $5 \times 10^{-14}$  to  $5 \times 10^{-10}$  coulombs. Total charge should be measured to an accuracy of approximately 5%. The measure of mass number separation  $\Delta M/M$  should be approximately 10% in order to identify hydrogenous, stone, and metallic particles.

### 3. Impact Flash Detection

The impact of a particle yields visible radiation which is measurable. The dynamic range for impact flash detection should be from  $4 \times 10^{-10}$  to  $4 \times 10^{-6}$  watts/steradian to an accuracy of approximately 5%.

### 4. Piezo-Electric Impact Sensing

A piezo-electric sensor should also be attached to the impact surface. This should have a limiting threshold for particle momentum of  $10^{-5}$  dyne-seconds. The accuracy should be 10% over 2 orders of magnitude before saturation. Experiments 2, 3 and 4 should be operated in coincidence to reduce spurious responses.

### 5. Photometric Measurements

Measurements should be made of the brightness in white light and the brightness and polarization in at least four colors. The filters should have a bandwidth of approximately 100 Å in several regions of the visible spectrum. Relative

brightness should be measurable from about five to one thousand tenth magnitude stars (visual) per square degree to an accuracy of approximately 1%.

C. Recommended Mission and Spacecraft Requirements

1. Trajectory Preference

a. The experiment scientific objectives deal with the near planet, interplanetary and interstellar environments.

b. With regard to the planetary objectives, JSUN presents a better opportunity for observation of Saturn's rings than JSP.

c. It is specifically recommended that at least one of the Outer Planets Missions be targeted through Cassini's division or the D' ring of Saturn to permit in situ measurement of particle concentration, size, and composition.

d. JSP is of interest because the post encounter trajectory is nearly in line with the apex direction of the Solar System.

e. Theoretical predictions of the particle belts around Jupiter are not good enough to warrant retargeting for particle belt observations in the vicinity of that planet.

f. From an engineering standpoint, large miss distances at Jupiter are preferable to avoid the potential radiation belt hazard.

It should be emphasized that no missions are excluded. Some are preferable to others with regard to the secondary scientific objectives.

2. Viewing (desired):  $4^{\circ}$  clear field-of-view with optic axis pointed  $30^{\circ}$  north and  $30^{\circ}$  east of anti-solar Z axis of spacecraft with capability of at least  $2\pi$  anti-solar mapping; minimize spacecraft structure which can scatter light into telescopes. Light shield design can accommodate a limited number of such scattering sources.

Viewing (to be avoided): Within  $30^{\circ}$  of the sun.

3. Required S/C Maneuvers

a. Description

Placing the sensor array on the scan platform obviates the need for any maneuvers. As an alternative, it would be possible to articulate the sensor array in one direction perpendicular to the roll axis of the spacecraft to allow for a minimum of  $2\pi$  steradian sky mapping in the anti-solar direction. It is then required that the spacecraft perform the roll as indicated below.

b. Rate

Maximum 0.5 revolutions per minute - Minimum 0.3 revolutions per hour.

c. Duration

40 revolutions.

d. Frequency of Occurrence

Approximately every two months.

e. When Needed.

Approximately every 0.5 au.

4. Commands

Articulation commands programmable. Electronic redundancy switching requires approximately 15 ground commands.

5. Potential Sources of Interference

Stray light into sensors which can be shaded against limited vehicle scattering sources but structures within  $90^\circ$  of telescope axes should be minimized.

6. Timing, Interface Signals, Spacecraft-Generated Commands

1 MHz or faster clock; spacecraft time to 1 second; commands for mapping attitude data to  $1^\circ$ ; analog to digital conversion within 100 milliseconds of random access.

D. Minimum Experiment for Grand Tour Per Project Constraints

PARAMETER

INFORMATION

1. Location

- |    |             |  |
|----|-------------|--|
| a. | Sensor      | Remote - on anti-solar side of antenna |
| b. | Electronics | Bus                                    |

2. Weight

- |    |        |               |
|----|--------|---------------|
| a. | Remote | 3 kilograms   |
| b. | Bus    | 1.5 kilograms |

3.      Size
  - a.      Remote      .5 x .5 x .5 meters
  - b.      Bus      .15 x .15 x .10 meters
  
4.      Orientation
  - a.      Field-of-View       $4^{\circ}$
  - b.      Preferred Viewing Direction(s)      Primary -  $30^{\circ}$  up and  $30^{\circ}$  right anti-solar roll axis.  
Mapping - minimum  $2\pi$  steradian anti-solar
  - c.      Scanning Rates       $3^{\circ}$  per spacecraft revolution stepped.
  - d.      A/C Stability      Less than  $0.1^{\circ}$  per hour.
  
5.      Power
  - a.      Remote      2w
  - b.      Electronics      5w
  
6.      Thermal
  - a.      Sensor
    - 1) Operating       $+75^{\circ}\text{C} > T > -200^{\circ}\text{C}$
    - 2) Non-Operating       $+75^{\circ}\text{C} > T > -200^{\circ}\text{C}$
  - b.      Electronics
    - 1) Operating       $+75^{\circ}\text{C} > T > -40^{\circ}\text{C}$
    - 2) Non-Operating       $+90^{\circ}\text{C} > T > -75^{\circ}\text{C}$
  
7.      Data
  - a.      Profile      1M bits/sec random access into buffer  
Maximum delay 100 msec.  
2K bits maximum
  - b.      Bits/Sec.      1 bit/sec average interplanetary  
10-bit/sec-average-during-encounter-and-sky mapping
  
8.      Mission Sequence       $2\pi$  anti-solar sky map required approximately every 0.5 au - can be accomplished with 1 degree articulation in conjunction with rolls - 30 revolutions minimum
  
9.      Other Constraints      Minimize sources of stray light into sensors



## VI.

### CHANGES IN PROJECT AND INVESTIGATION DIRECTION

The Outer Planets Missions Program underwent a major change in direction in December of 1971. The Grand Tour Missions were cancelled and plans for the Mariner-Jupiter-Saturn 1977 Missions were initiated. A major scientific objective of these latter missions was the investigation of Saturn's rings during close proximity planetary flyby. The spacecraft and subsystems which were to perform these missions were far less ambitious than those of the TOPS vehicles. Fiscal constraints were far more severe. The foregoing made necessary some changes in the priorities of the science objectives of the Meteoroid Science Team. Reflecting the prime objective of Saturn ring measurements, the team requested that it be cited as the "Particulate Science Team". Further, implementation of the reordered science objectives in the form of instrument hardware was bound by a revised set of constraints. On the one hand, certain specifications were relaxed. For example, the radiation susceptibility requirement was relaxed since the MJS '77 spacecraft would pass no closer to Jupiter than approximately six planetary radii. The reliability specifications were also relaxed since the prime mission lifetime was reduced from 10 to 4 years. On the other hand, the fiscal constraints dictated using previously developed hardware with minimum power requirements. This led the team to abandon earlier concepts which would integrate the various detection schemes into a single sensor package since such concepts involved extensive development programs. At the same time, additional impetus was given to abandoning the single sensor package concept. It became increasingly apparent that the photometry required a minimum of  $2\pi$  sky coverage and preferably more. Articulation of a single large sensor package placed too great a weight and power burden on the spacecraft. Further, after intensive investigation with project personnel, it was concluded that the requisite sky coverage could not be achieved with fixed optics operating with the constraints of possible spacecraft maneuvers.

Early in 1972 there appeared several theoretical and experimental indications of microparticles with velocity vectors directed from the solar vicinity (Hemenway et al., 1972, Gerloff and Berg, 1972). Positive verification of these "solar vicinity microparticles" and a determination of their source could be obtained by measuring the flux as a function of heliocentric distance. To measure these "solar vicinity microparticles" and provide the relationship with interstellar particles required that the impact sensors have virtually a  $2\pi$  planar acceptance angle in the invariant plane of the solar system.

With all of the foregoing in mind the science objectives of the particulate investigation were revised to emphasize the new priorities. The proposed instrumentation to meet these objectives was also revised. The balance of this report is devoted to describing the now proposed investigation which was renamed "Integrated Light Ionization Acoustic Detectors" (ILIAD). This is also a summary of the team's activities during the balance of the definition phase of the Outer Planets Missions Program.

#### A. Scientific Objectives for the MJS '77 Missions

The overall objective is an extensive multiparameter study of the evolving and primordial particulate matter originating in or transiting the solar system

and the dynamic interactions of this material with solar and planetary forces. The parameters to be studied include the orbital elements, size, mass, density, composition and spatial distribution of individual particles, and the photometric parameters of aggregates of particles. The primary specific objectives are:

1. To investigate the rings of Saturn to determine their properties and to establish the relationship between the rings and the planetary environment (meteoroid, magnetic, trapped radiation, solar radiation, and satellite resonances).
2. To perform comparative studies at Jupiter (particularly in the equatorial plane of the planet) in search of predicted rings of particulates.
3. To study the cometary and asteroidal complexes and their interactions with solar and planetary (especially Jovian) forces to determine the nature, origin and evolution of these important constituents of the solar system. To determine whether these complexes are the result of grinding, accretion or sublimation processes.
4. To perform direct measurements of the spatial density, heliocentric distribution, velocity, mass and, possibly, the composition of interstellar grains transiting the solar system. The heliocentric variation caused by interaction with the solar gravity, wind and electromagnetic radiation is of particular interest.
5. To study particles coming from the general direction of the sun and determine how their distribution changes with increasing heliocentric distance.
6. To study areas of known and suspected diffuse light enhancements in the absence of scattered light from atmospheric and interplanetary sources to better characterize their origin. Of particular interest are the interstellar grains, cosmic light, and extra-galactic light and photometric enhancements at the libration regions of Jupiter and Saturn.

#### B. Results Anticipated

1. Particulate matter in orbit about Saturn plays a critical role in the interaction of that planet with its environment. An understanding of the planetary interaction with the solar wind cannot be achieved without a knowledge of such orbiting material. As an example, it has been hypothesized that Saturn has a permanent magnetic field (Newburn, 1969). The absence of radio emissions is laid to a lack of trapped radiation in the inner L shells. The ring particles present recombination surfaces to protons and electrons that become trapped in the magnetic field. If trapped radiation exists in the outer L shells, then its nature and distribution will depend heavily upon the particulate population passing through those shells. On the other hand, the planetary environment can determine the long term stability of the rings. A magnetic field will produce drag forces on either charged particles or particles capable of carrying eddy currents. Another model (Cook, et al., 1971) holds that collisions with the local cometary meteoroid flux is the prime determinant of the long term stability of the rings.

The investigation will allow one to choose between conflicting theoretical models for the Saturnian rings. The various in situ sensors will determine the composition, size, mass and orbit of the D' (exterior to ring A) ring particles and make the same determinations for those particles scattered out of the inner rings. From a combination of surface photopolarimetry and stellar occultation measurements, one will be able to resolve theoretical models of the inner ring population. Existing models predict everything from kilometer-sized boulders in rolling contact (Cook, et al., 1971) to submicron-sized particles (Price, 1970). The investigation will also determine the composition and material properties of the ring particles. The combination of in situ and remote measurements are required to identify complex particles (e.g. ice coated stone) and characterize the particle properties to the degree required for an understanding of the interaction between the rings and the environment.

Comparative measurements will be performed at Jupiter where optically thin rings may be encountered. The existence of Jovian radio emissions argues against sizeable particulate interference with the inner L shells. Orbiting particulates are more likely to be found in the vicinity of the inner Jovian satellites where they may be trapped from the asteroid belt. Hence the MJS '77 trajectories are better suited to particulate investigations at Jupiter than that of the Pioneer 10 spacecraft which will cross the Jovian equatorial plane with large inclination ( $\sim 30^\circ$ ) at 3 Jovian radii.

2. The composition, spatial distribution, size distribution, mass distribution, orbit distribution, densities, and photometric parameters will be determined for the interplanetary meteoroids. These measurements will be used to distinguish between cometary, asteroidal and primordial origins.

The present state of the interplanetary debris provides a critical test to many of the theories for the evolution of the bodies in the solar system. Debris in collisional equilibrium can be expected to have a characteristic size or mass distribution (Dohnanyi, 1971). This would be expected to differ from the distribution produced by an accretion process or a recent catastrophic event. Thus, an accurate representation of the mass and size distribution as a function of orbit can be expected to shed new light on theories of the formation of the solar system or portions thereof (e.g. the asteroids).

The origin and evolution of comets remains a mystery. The finite life-time of the observable comets (short compared to the age of the solar system) dictates a source beyond Jupiter. Information on the interplanetary debris at large heliocentric distances can provide important clues to that source. Meteoric streams that do not intersect the Earth's orbit will likely be encountered. The cometary belt predicted beyond 10 au (Whipple, 1955; Lindblad, 1972) may even be discovered.

Compositional measurements of cometary and asteroidal particles can resolve the questions of the origin of meteorites and of the nature of fireballs that do not yield recoverable fragments.

The "Jupiter Barrier" theory (Opik, 1951), which predicts a dramatic increase in particle concentration beyond the orbit of Jupiter, will be tested. This is partly a special case of the "planetary sweeping effect", which preliminary data from Pioneer 10 indicate may have already been observed at the Mars crossing. Comparative measurements will also be made in crossing the orbit of Saturn. The rate of planetary sweeping is proportional to the lifetimes of the particles. Measurements of the fraction of particles swept out by each planet over a large range of particle sizes (from 0.1 micron to centimeters) combined with the size, mass and orbital information should yield the mean density of the interplanetary dust.

3. A search will be made for dust clouds or other "bright blobs" of the type that have been reported by several ground based observers and from the OSO-6 photometry experiment (Roosen and Wolff, 1969; Roach, 1972). The libration points of Jupiter and Saturn will be of particular interest since better information on the particulate concentration can be obtained with the aspect angles available from an outer planets probe.

4. Experimental evidence exists for particles which travel in hyperbolic orbits from the solar vicinity (Berg and Grun, 1972). These particles could be generated by the sun (Hemenway, et al., 1972), be the residue of particles which spiraled into the solar vicinity, were partially evaporated and then blown out again (Belton, 1969), or be particles generated from sun-grazing comets (Silverberg, 1970). The proposed investigation will determine the mass and spatial distribution of such particles as a function of solar distance; information which can distinguish the correct theoretical model.

5. The existence of interstellar grains (distributed diffusely and concentrated in clouds) has been determined from stellar extinction and polarization measurements. Small particles with hyperbolic orbits that come from the direction of the solar apex have recently been reported (Gerloff and Berg, 1972). Mass distribution, composition and the spatial concentration can only be determined by direct, in situ measurement. The determination of these parameters will allow astrophysicists and cosmologists to distinguish between hypothesized source mechanisms and to describe the nature of the heliosphere boundary.

The absolute brightness of the Milky Way will be mapped in the absence of scattered light from atmospheric or interplanetary sources. Because of the decrease in the intensity of solar illumination with heliocentric distance, the intensity of scattered light from interplanetary material must become negligible in the outer solar system. Measurements of the intensity, polarization and color of diffuse galactic light obtained under these unique conditions will provide vital information on the nature and concentration of interstellar grains; information that is independent of that obtained from extinction and polarization measurements of starlight. Only under these conditions is the cosmic light (integrated light from extra-galactic sources) amenable to measurement.

### C. Approach and Instrumentation

A single team proposal for several complementary detectors reflects a recommendation made by the Outer Planets Missions Science Steering Group (Mission Definition Phase MJS '77 document 618-8, 5/15/72, p. 8). As described below, the resulting investigation provides a synergistic effect in that parameters can be determined or inferred from the combination of measurements that cannot be determined by any one of the detectors above.

The integrated instrumentation proposed for the ILIAD consists of a Microparticle Ionization Analyzer which incorporates an impact ionization mass spectrometer, a large particle optical detector (Sisyphus), a Combined Light Flash and Acoustic Micrometeoroid Detector which is incorporated in one of the Sisyphus telescopes, and a Photopolarimeter which is incorporated in another of the Sisyphus telescopes. In this section these portions of the instrumentation are treated separately. To allow a logical presentation, the "approach" and "instrumentation" discussions are combined for each of the detectors. Their scientific and hardware interdependence are pointed out where appropriate.

ILIAD incorporates modified versions of instruments developed for the Pioneer 10/G, HEOS A-2, HELIOS, and Skylab programs. Maximum use is made of information and data reduction techniques developed for these various programs and for the definition phase of the Outer Planets Missions Program. As an example, breadboarded electronic circuits and components were irradiated at levels far more severe than are likely to be encountered during the MJS '77 missions. Should Pioneer 10 encounter higher radiation levels at Jupiter than predicted, the effect on the instrumentation can be readily evaluated and the previously developed corrective measures can be rapidly implemented. The proposed instrumentation is designed to obtain the maximum science from the MJS '77 missions within the constraints imposed by the project. Prime consideration has been given to minimizing cost and power consumption consistent with maximum reliability and scientific yield. In keeping with the Outer Planets Missions Project guidelines, cost-weight trade-offs have resulted in major cost reductions. Thus, it should be borne in mind that the proposed configuration represents a fiscal rather than a weight minimum. Additional weight reductions are possible at increased cost.

#### 1. Microparticle Ionization Analyzer

The Microparticle Ionization Analyzer consists of three units, each optimized in terms of pointing direction, sensitivity, dynamic range, and other factors to contribute information on specific components of the particulate complex. The basic principle behind all three units is the impact ionization effect first observed several years ago (Friichtenicht and Slattery, 1963) and subsequently examined extensively in the laboratory (e.g., Hansen, 1968; Auer and Sitte, 1968). An impact ionization detector is in operation on the HEOS A-2 spacecraft and an impact ionization mass spectrometer is being built for the HELIOS spacecraft scheduled for launch in 1974 (Dietzel, et al., 1972).

Upon impacting a surface, a hypervelocity particle produces an "impact plasma", which contains ions, atoms, and molecules of both the impacting particle and the target material. Application of an external electric field separates the positive and negative charges. Charge of either species may be collected on either the impact surface or on a parallel grid and used as a simple impact detector, or the ions may be accelerated and mass-separated by their time of flight to a remote collector. The magnitude of the collected charge is proportional to the mass of the impacting particle, and the rise time of the signal at the impact target provides information on the impact velocity. In order to increase the reliability of the data from the units, at least two signals are measured in coincidence from each; that is, the electron charge pulse at the target and the ion charge pulse at the grid in front of the target. Since the occurrence of simultaneous impacts on two of the units is extremely unlikely, a logical constraint built into the instrumentation records the absence of signals from the other two units when an impact occurs in any of the three. All data is recorded and telemetered. Thus, if extremely high impact rates occur at Saturn ring plane crossing, no data will be lost. The finite resolution time of the units ( $\sim 100 \mu$  sec for the IIMS) does, however, set an upper limit to the inter-event spacing.

Two of the units are impact ionization detectors (IID's) consisting basically of a biased impact plate and parallel grid. Signals are obtained from both the target and grid and simultaneous signals are required to validate an event. The signal is pulse height analyzed with an overall dynamic range of  $10^6$ . The velocity of the particle is determined from the rise time measurement. IID(1), with an acceptance angle of  $120^\circ$ , is directed toward the  $-Z$  spacecraft axis (approximately the solar direction) for the primary purpose of studying the spatial variation and mass distribution of particles from the inner solar system. A gridded aperture of approximately 10 cm diameter is required in the antenna for this unit. The location and pointing direction of IID(2) (20 cm diameter,  $120^\circ$  acceptance angle) has been optimized for interception of interstellar particles. The pointing requirements of both units are discussed in Appendix H. The functional characteristics of the two IID's are identical.

The target assembly of the impact ionization mass spectrometer (IIMS) is similar to the IID's but is 30 cm in diameter. Ions emitted from the target are accelerated and drift through a field-free region to the ion collector. The transit time of an ion depends upon its atomic mass and the collector signal consists of a series of charge pulses each corresponding to a given element from the particle or target. The resolution ( $m/\Delta m$ ) attainable depends on atomic mass, accelerating potential, length of the drift space, and the rate at which the collector signal is sampled. The proposed instrument, carefully optimized within the constraints of the MJS missions and confirmed by laboratory tests, uses a drift length of 80 cm and an accelerating potential of 1000 volts. The spectrum range is from 1 to  $\sim 200$  amu and the resolution is about 10 in the 20 to 60 amu range with is adequate to resolve the major elements expected. Relative amplitudes of individual peaks will be determined within a factor of two or better over the entire dynamic ionization range of  $10^6$ .

The location and pointing direction of the IIMS (generally along the  $+Z$  axis) has been chosen for optimum results from Saturn ring and asteroidal particles.

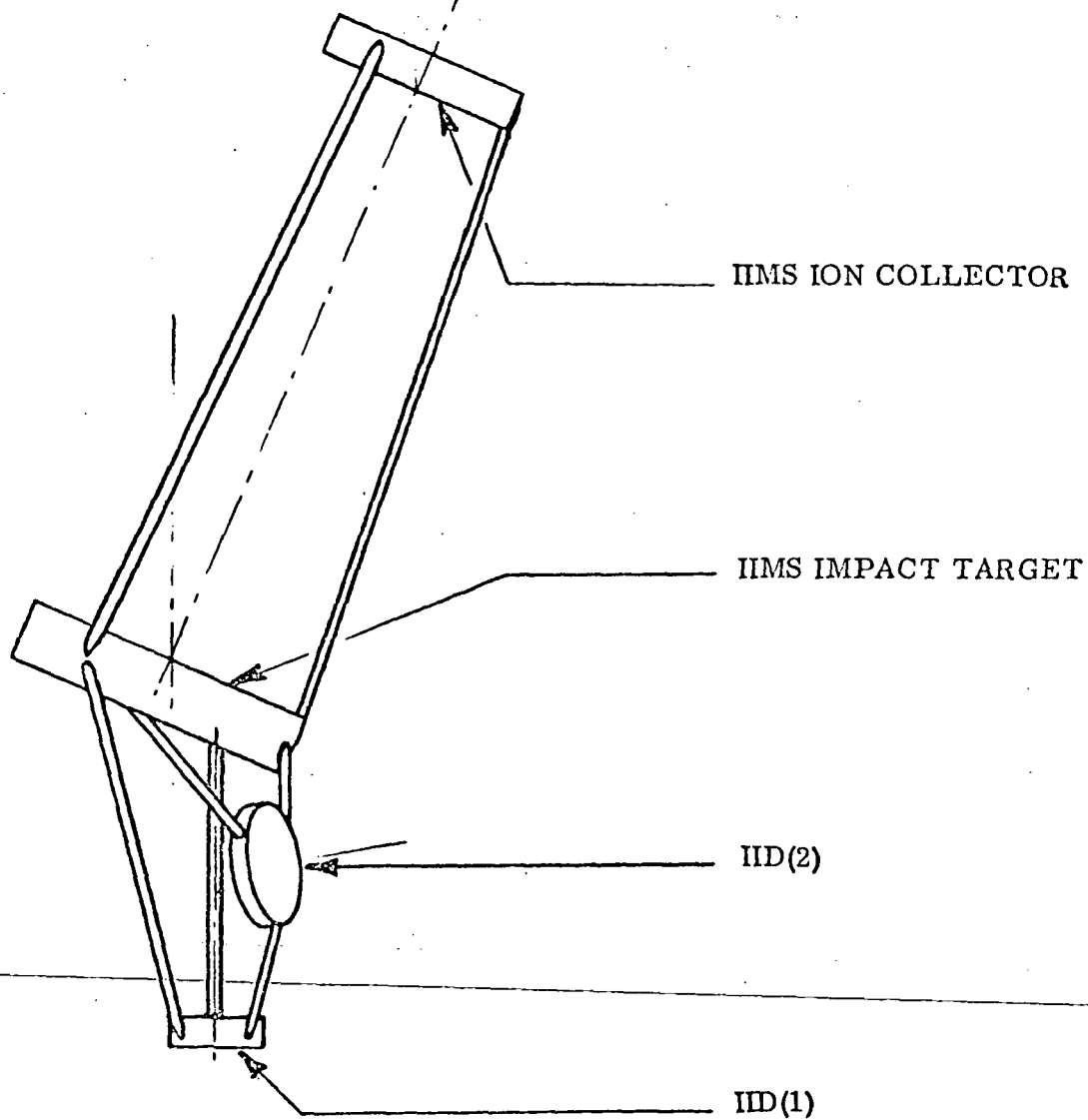
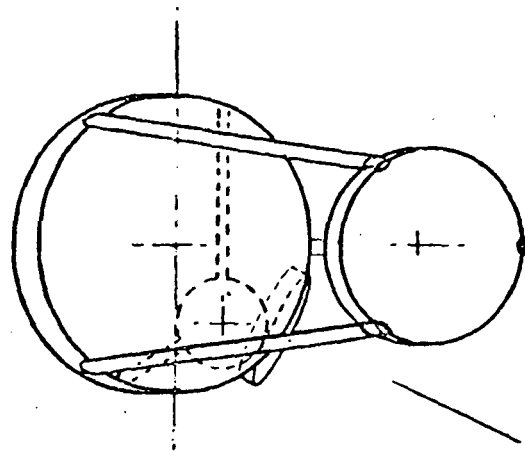
As discussed in Appendix H, a single pointing direction is satisfactory for both sample Saturn encounter trajectories. The angular acceptance range is about  $120^\circ$  (near-normal trajectories are excluded). All three units will sample a portion (determined by orbital parameters) of the interplanetary meteoroid complex and, together, cover almost all of the ecliptic plane.

The sensitivity of these detectors is determined by the amount of charge produced which is a function of the particle composition and velocity. In the 15 to 20 km/sec range an average value is about 1 coulomb/gm. With a conservative discrimination level of  $10^{-14}$  coulombs, the particle mass threshold is  $10^{-14}$  grams. Because of charge separation in the mass spectrometer unit, the charge collected per unit time is smaller and the detection threshold for composition analyzed particles is about a factor of ten greater than for the IID's at the same signal-to-noise ratio. To accommodate a large range of particulate masses, all three units are designed with a dynamic range of  $10^6$  giving a detectable mass range from  $10^{-14}$  to  $10^{-8}$  gms for the IID's and from  $10^{-14}$  to  $10^{-7}$  gms for the IIMS.

The number density of interstellar grains is estimated (Allen, 1963; Greenberg, 1969) to be between  $10^{-12}$  and  $10^{-13}$   $\text{cm}^{-3}$ . Pioneer 8 and 9 measurements (Berg and Grün, 1972) give a number density of interplanetary particles with  $m \geq 10^{-12}$  gm of  $2 \times 10^{-14}$   $\text{cm}^{-3}$  at 1 au. The impact rate in the asteroid belt is about the same judging from early Pioneer 10 data. The Pioneer 8 and 9 measurements (Berg and Grün, 1972) also give a flux of "solar vicinity" particles of  $8 \times 10^{-4}$   $\text{m}^{-2} \text{sec}^{-1}$  ( $2 \pi \text{sr}$ ) $^{-1}$  at 1 au. Estimates of the population in or near the Saturn D' ring differ by too much to be of analytical use. The above considerations yield the following estimated event rates:

- a. Saturnian Ring particles, mass analyzed: from a few to hundreds
- b. Asteroidal particles, mass analyzed:  $\sim 2/\text{day}$
- c. Interplanetary particles, mass analyzed:  $\sim 2/\text{day}$
- d. Interstellar particles [IID(2)]:  $\sim 3/\text{day}$
- e. Solar particles [IID(1)]:  $\sim 1/\text{day}$

The mechanical configuration of the MIA is shown in Figure 3. The pointing angles of the three units discussed in Appendix H are critical to only about  $\pm 5^\circ$ ; of course obscuration by other parts of the spacecraft is to be avoided. It is necessary to have a gridded aperture in the antenna for the Earth-viewing detector. The location on the spacecraft shown in Figures 4 and 5 appears feasible and satisfactory, but others are possible.



SCALE

0 20 40 60

CENTIMETERS

FIG. 3

MICROPARTICLE IONIZATION ANALYZER FOR MJS'77



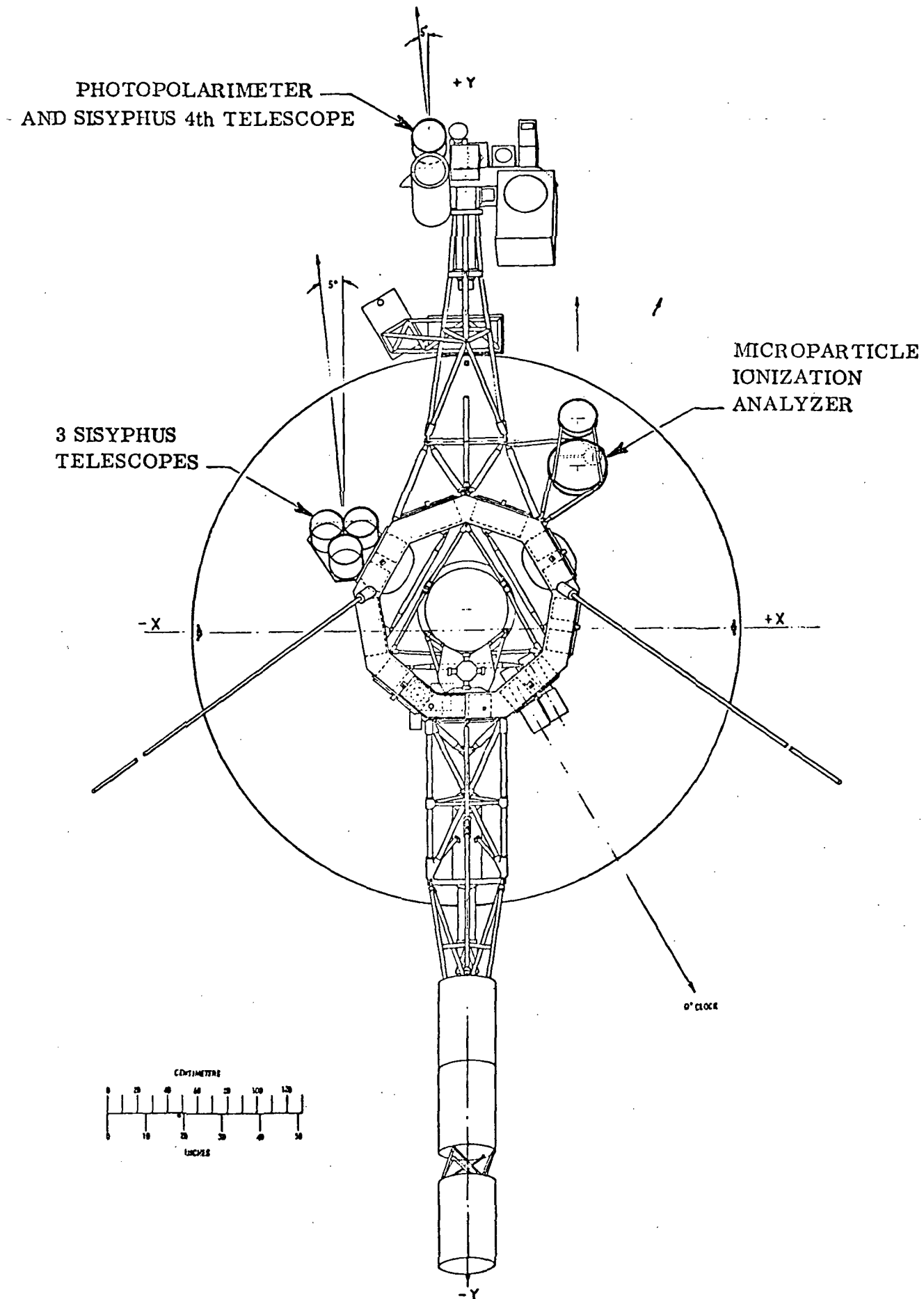


FIG. 4

ILIAD INSTRUMENTATION ON MJS '77

PHOTOPOLARIMETER  
AND SISYPHUS 4th TELESCOPE

MICROPARTICLE IONIZATION  
ANALYZER

3 SISYPHUS  
TELESCOPES

TO EARTH  
(TOWARD SUN)

+Z

-Z

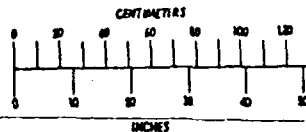


FIG. 5

ILIAD INSTRUMENTATION ON MJS '77

For this detector heavy stress is laid on noise suppression and recognition of false events by measuring various coincidences, applying plasma-suppression grids in front of each unit and by shielding from potential noise sources. These methods have been developed for the HEOS A-2 and HELIOS instruments.

A block diagram of the electronics is shown below in Figure 6. The IID(1), IID(2), and IIMS share command logic, test pulse generator, power conditioning circuitry, and parts of the buffer memory. Amplitude and rise time data from IID(1) and IID(2) are quantized and stored in the memory for later transfer to the Flight Data Subsystem (FDS). Only the amplitude data from the IIMS target and grids is similarly conditioned. Amplitude data is recorded in 5 bits, with a dynamic range of 6 decades. Rise time is recorded with 4 bits, including dynamic range. There are several coincidence-indicating circuits included to increase the reliability of true-event counting. If the buffer memory is full, then the total number of unprocessed events is counted. Also, noise counts (i. e., those that do not fulfill the coincidence requirement) are recorded.

Processed events are time-tagged and identified by detector source. The event and noise counter data and the identification bits and time tag are all stored in the buffer memory. Data from each impact detector requires about 64 bits total. Housekeeping and spacecraft time data require approximately another 32 bits.

The signal from the ions arriving at the IIMS collector is time-sampled and the amplitude of the signal in each channel is quantized. A total of 256 bits is required for each spectrum. At each telemetry (FDS) readout time, the spectrum data, IID(1), IID(2) and IIMS target data are recirculated in the buffer memory. Portions are replaced by new data when a new event takes place, provided the first event has been read out to the FDS. If no new event takes place, the same data are again read out at the next FDS time. A mean telemetry bit rate of 0.5 bits/sec should be adequate for all but the Saturn encounter, where 50 bits per second for 20 hours ( $\pm$  10 hours of ring plane passage) is required. Impact ionization data should be in the real-time telemetry stream for hazard evaluation should the spacecraft malfunction after ring passage.

Test pulses are generated upon command to provide checkout and in-flight calibration capability. The test pulses are applied directly to the amplifier inputs. The 2400 Hz square wave spacecraft power is conditioned to provide all necessary voltages, including the 1000 volts at the IIMS target. Power requirements from the spacecraft will not exceed 2.6 watts (average).

## 2. Sisyphus

The Sisyphus concept for particle measurement has been described in the literature (Grenda, et al., 1970). Solar radiation reflected from the particle is used for detection, range and velocity determination. Three optical systems, coupled to photomultipliers and having overlapping conical fields of view, detect sunlit particles passing through the overlap region. The times of entrance into and exit from the three cones are utilized to completely determine first, the particle's trajectory relative to the instrument, and then its orbit in the solar system. An "albedo cross-section"

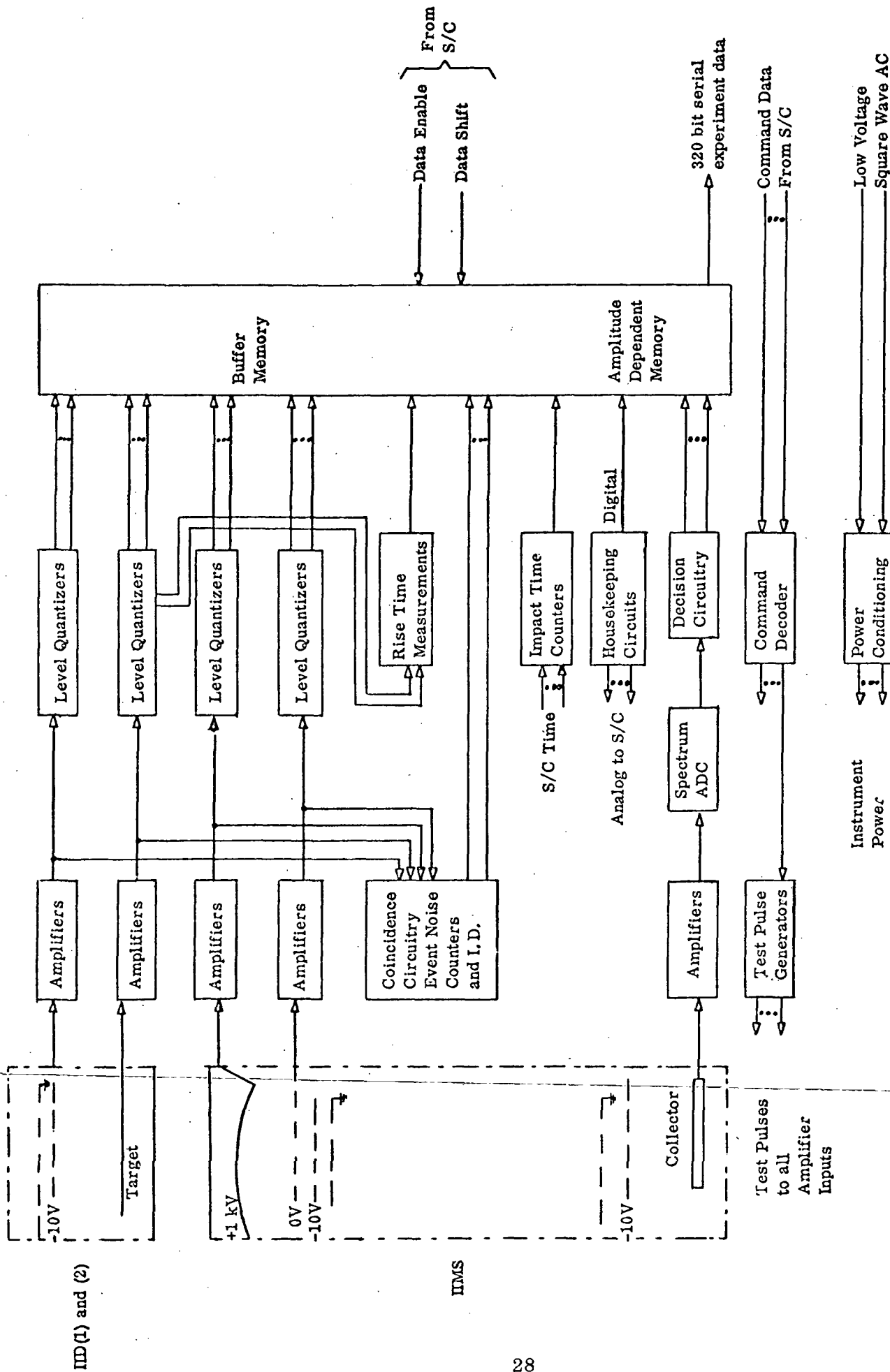


FIG. 6 MICROPARTICLE IONIZATION ANALYZER SYSTEM DIAGRAM

equal to reflectivity times the illuminated cross-sectional area is determined from the calculated range and measured irradiance. Such an instrument is in operation on the Pioneer 10 spacecraft.

The addition of a fourth telescope has been shown in Pioneer studies to add more than 20% in overall reliability and a factor of 2 in data accuracy (when an event is detected in all four). Consequently, an additional telescope is considered essential for the MJS '77 mission. Since the Sisyphus concept operates on what is basically a parallax principle, increasing the separation between telescopes further improves the accuracy of the data. It is proposed that the fourth telescope be placed approximately 2.5 meters from the others. Studies show a factor of 2 average improvement in orbit determination for those particles that pass through the overlap region. Coincident detection with this fourth telescope will occur only for those larger (or brighter) particles beyond 35 meters (for the  $2^\circ$  half angles proposed) from the instrument. The remaining telescopes will be capable of detecting particles to within approximately 2.5 meters (the distance out of the shadow of the spacecraft antenna.)

It is proposed that the fourth Sisyphus telescope also be used for photopolarimetry measurements (see Section VI. C4). For this purpose it should be mounted on the scan platform. When not being utilized for sky mapping, ring studies, etc., it should be left in a "cruise position" which is aligned to within  $20'$  of the optic axes of the remaining three telescopes. Alignment and intensity calibration is discussed below. In addition, one of the spacecraft fixed telescopes will also be capable of measuring the mass and velocity of microparticles that impact the primary mirror. This is done by sensing the coincident light flash and acoustic signal (see Section VI. C3).

A major objective of the Sisyphus detection system is the measurement of Saturn ring particles (those in the D' ring and those driven out of the inner rings by collisional processes). It should be pointed out that one of the sample trajectories (JST) crosses the ring plane in the shadow of the planet, making it impossible for the Sisyphus detector to properly function at that time. It appears possible to accomplish the major objectives of that mission (Titan flyby, Saturn occultation, high inclination passage) while crossing the ring plane in sunlight. The three spacecraft-fixed telescopes will be looking away from the planet and the rings at passage, thus providing a low background (and consequently high sensitivity level).

In connection with Saturn ring measurements it has been suggested that the Sisyphus detector can be confused by simultaneously "seeing" two or more particles. While it is true that two or more particles bright enough to exceed the instrument threshold would result in misleading data, this is only a transitory phenomenon. When the particle population becomes large enough to continuously include several particles in the field of view they are treated as part of the background. The self-setting threshold is raised, and only the brighter particles that can exceed this new threshold are recorded as discrete "events".

Apart from the inclusion of light flash and acoustic sensing in one telescope and a photopolarimeter in another, several other modifications have been

made to the existing Pioneer 10/G Sisyphus instrument which will improve the sensitivity and reliability, thus increasing the number of detected particles and improving the statistics. The output of each of the photomultipliers will be simultaneously analyzed by 3 electronic channels of differing bandwidths (instead of the Pioneer 10/G Version which can change bandwidth only by ground command). This subdivision of signal serves the two-fold purpose of adding reliability (in the event a channel fails) and providing a wide dynamic range of signal sensitivity. Bandwidth reduction, while increasing sensitivity, decreases the accuracy of the velocity data and is therefore most useful for measuring smaller particles that are moving slowly relative to the spacecraft. The coincidence logic has been modified for multiple bandwidth sensing and to allow for two telescope coincidence measurements by ground command if one spacecraft fixed telescope fails and the scan platform telescope cannot be boresighted with the remaining two.

Additional sensitivity is gained by taking advantage of the three-axis stabilization of the MJS '77 vehicles. Three of the telescopes maintain fixed orientation with respect to the spacecraft (the fourth takes this same orientation for most of the cruise phase). The orientation (see Appendix H) is chosen to minimize the star background and, consequently, the photon noise which is a limiting factor to the Sisyphus system. The field of view has been narrowed to a  $2^\circ$  half angle (from the present  $3.75^\circ$ ) to increase the effective range. Improved shielding against stray light and mirror spectral characteristics (see below) will also provide additional sensitivity without significantly increasing cost, weight or power consumption.

While new fabrication techniques for larger aperture, lighter weight mirrors were shown to be feasible during the definition phase of the Outer Planets Missions, fiscal considerations dictate retaining the current fabrication techniques with a 20 centimeter aperture Ritchey-Chrétien version of a Cassegrain telescope. Better optical spectral response is obtained by the use of aluminum coated rather than gold coated lightweight mirrors. The feasibility of utilizing the aluminum coated mirrors was demonstrated during the definition phase of the Outer Planets Missions and is a minor additional step in the fabrication process. The telescope characteristics are shown in Table 1.

The RCA 7151Q photomultiplier tube with S-20 photocathode response will also be retained. Experience gained with this tube during the Pioneer 10/G program (particularly in the Jovian radiation environment) will be extremely useful. Another minor modification is the change to a fused silica end window (to allow for ultraviolet zodiacal light measurements). The electronics will maintain the use of RCA COSMOS logic circuits but without the costly hybrids currently in use on Pioneer 10/G (one of the significant cost-weight tradeoffs). Pioneer Project studies have shown that these logic components should survive the nominal Jovian radiation model at the closest approach planned for the MJS '77 missions. This radiation susceptibility will be tested during the Pioneer 10 Jupiter encounter in late 1973. It might be pointed out, however, that the currently available COSMOS have been improved with respect to radiation hardening from the early versions procured for the Pioneer Program.

A sketch of one of the three spacecraft fixed telescopes is shown in Figure 7. A block diagram of the Sisyphus electronics is shown in Figure 8. The instrument location shown in Figures 4 and 5 is satisfactory and appears feasible but others are possible. It should be noted that, as with other optical instruments, stray light suppression is exceedingly important. The size and weight of the stray light shields surrounding the telescopes will depend critically on the instrument location relative to other instruments and spacecraft components. The total field-of-view requirement of  $4^\circ$  is negligible compared to the scattered light limitation. The optical axes should be pointed  $25 \pm 5^\circ$  from the spacecraft XZ plane toward the + Y axis and  $5 \pm 2^\circ$ ,  $- 0^\circ$  from the YZ plane toward the - X axis. The choice of this pointing angle for the sample trajectories is discussed in Appendix H.

The sensitivity of the Sisyphus instrumentation in terms of range-to-radius ratio for the MJS '77 trajectory as a function of solar distance is shown in Figure 9 where it is compared to the mean performance achieved with the Pioneer 10/G instrument. The bond albedo assumed is 0.2. Early data from Pioneer 10 indicates that this is probably a conservative assumption. Based on the early Pioneer 10 data which yielded approximately one event per day to the Mars orbit, an event rate of 4 per day at the widest bandwidth can be anticipated for the early part of the mission, and at the narrowest bandwidth as many as 25 per day can be anticipated. Extrapolation of the early Pioneer 10 data to large solar distance is exceedingly premature and potentially misleading in view of the assumptions required; however, earlier predictions should be revised upward. Conservatively, one might expect an event rate of approximately one per week at 10 au before Saturn encounter. At the narrowest electronic bandwidth the minimum detectable particle radius at 1 au is approximately  $5 \mu\text{m}$  which gives a considerable particle detection overlap with the microparticle impact sensors. This minimum detectable particle radius will increase to approximately  $35 \mu\text{m}$  at 10 au.

Sisyphus data requires 256 bits per event. An average bit rate of 0.5 bits per second should be adequate for the highest anticipated event rate with the exception of calibration and Saturn encounter (see below). The data for the most recent three events, appropriately time tagged, and the information from three event accumulators with a total of 12 bits, is retained by recirculation in the buffer memory and telemetered continuously. The instrument overwrites this with new data when events occur.

Calibrations will be performed utilizing known stars primarily during the planned roll maneuvers at 0.5 au intervals. During these maneuvers, amplitude data from the four telescopes will require approximately 10 bits per second of real time telemetry at a roll rate of 3 mr/sec. Real time data reduction will enable the instrument to be commanded into a high bit rate mode for determining misalignments to approximately 0.15 mr. At this high bit rate mode, snapshot data should be accumulated for twelve seconds at the entry and exit of a star. A data rate of approximately 320 bits per second will be required for a minimum of two twelve second intervals (a total of 7680 bits) per revolution. These can be telemetered at any convenient rate. Such data should be obtained for a minimum of five spacecraft revolutions. A scheme less burdensome to the spacecraft is to treat calibration stars as very long "events". This is the method being employed on Pioneer 10. The much slower roll rate of the MJS '77 spacecraft

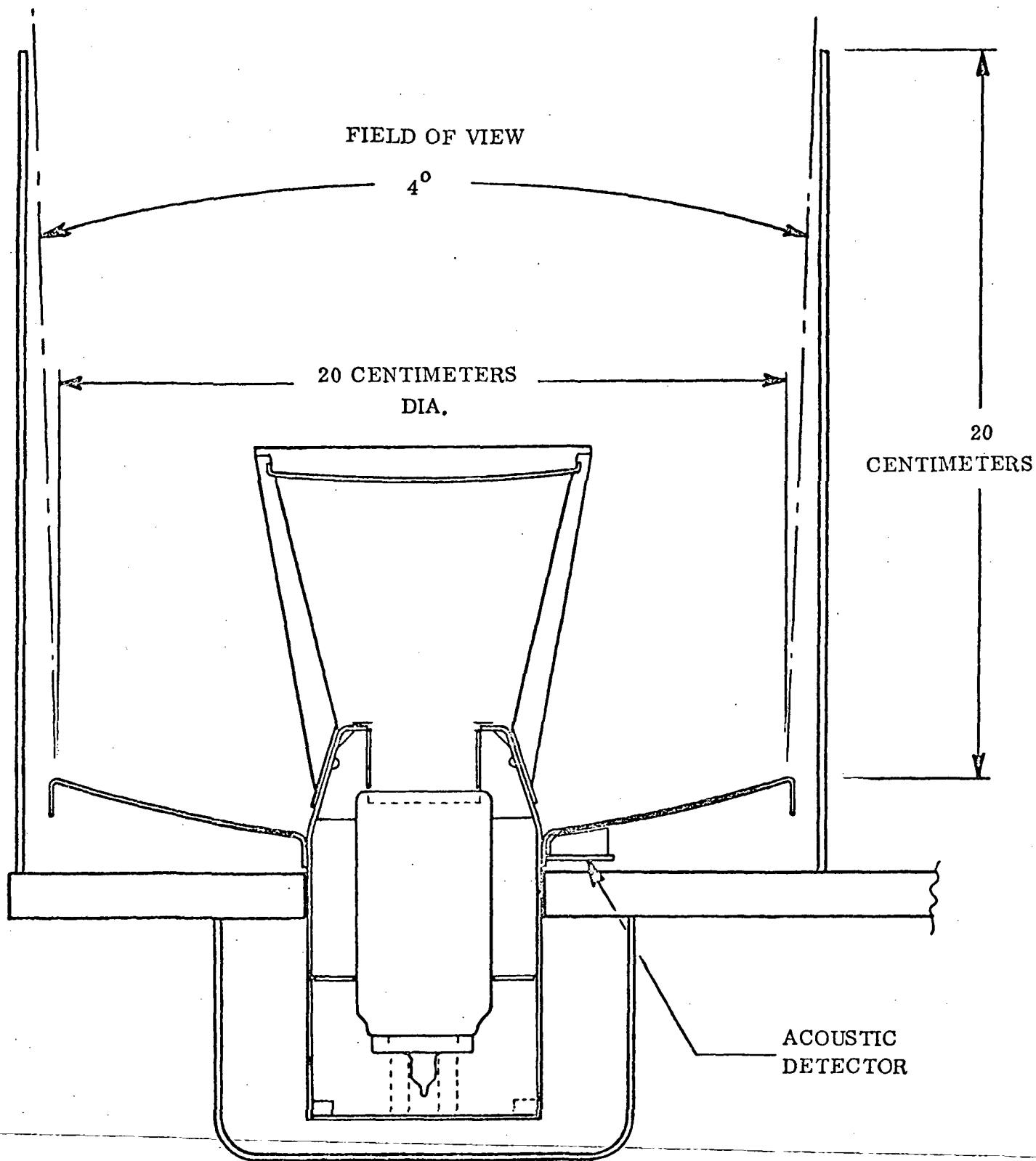


FIG. 7

SISYPHUS TELESCOPE EQUIPPED FOR  
IMPACT FLASH-ACOUSTIC DETECTION



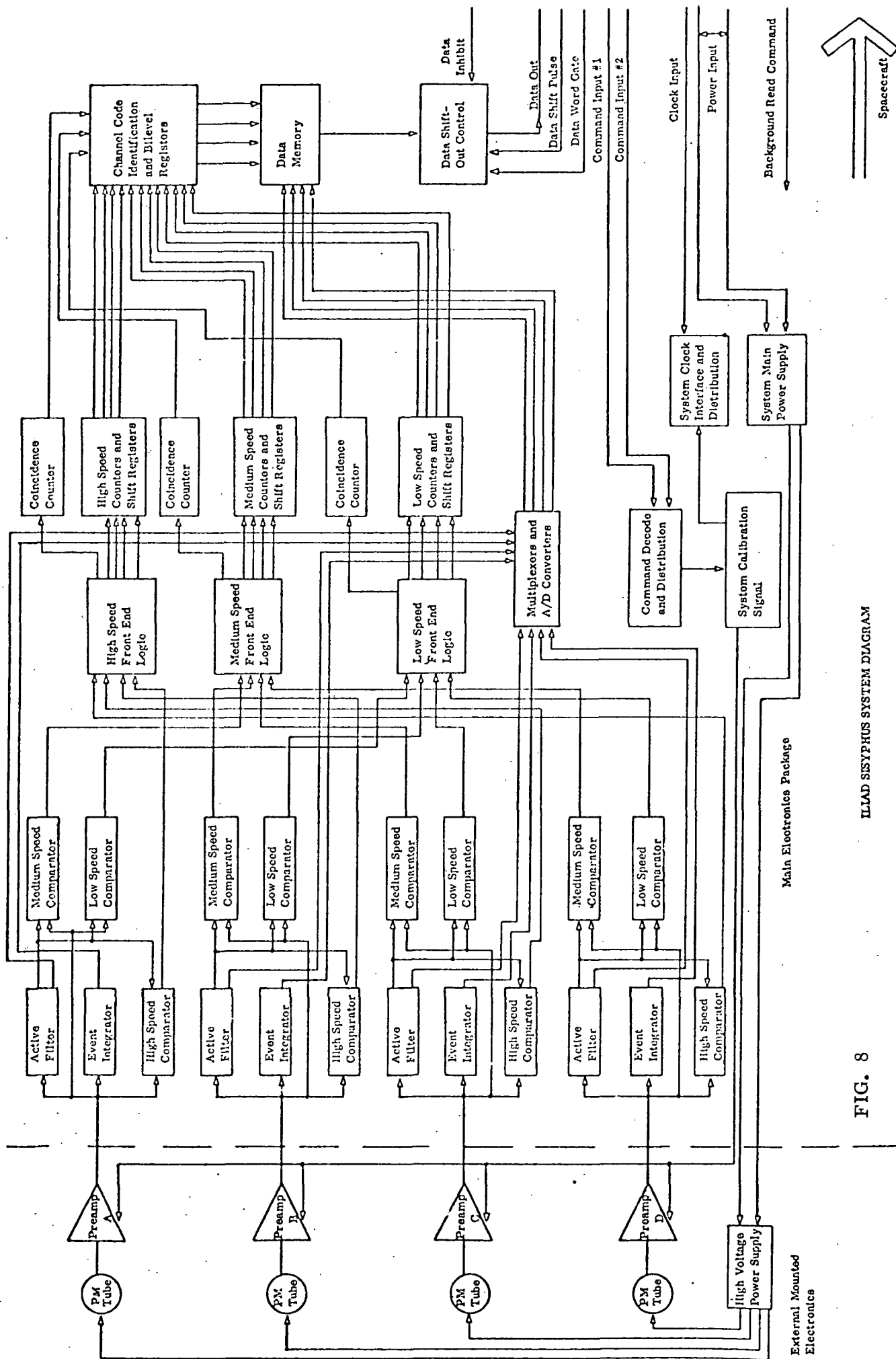


FIG. 8

ILIAD SISYPHUS SYSTEM DIAGRAM

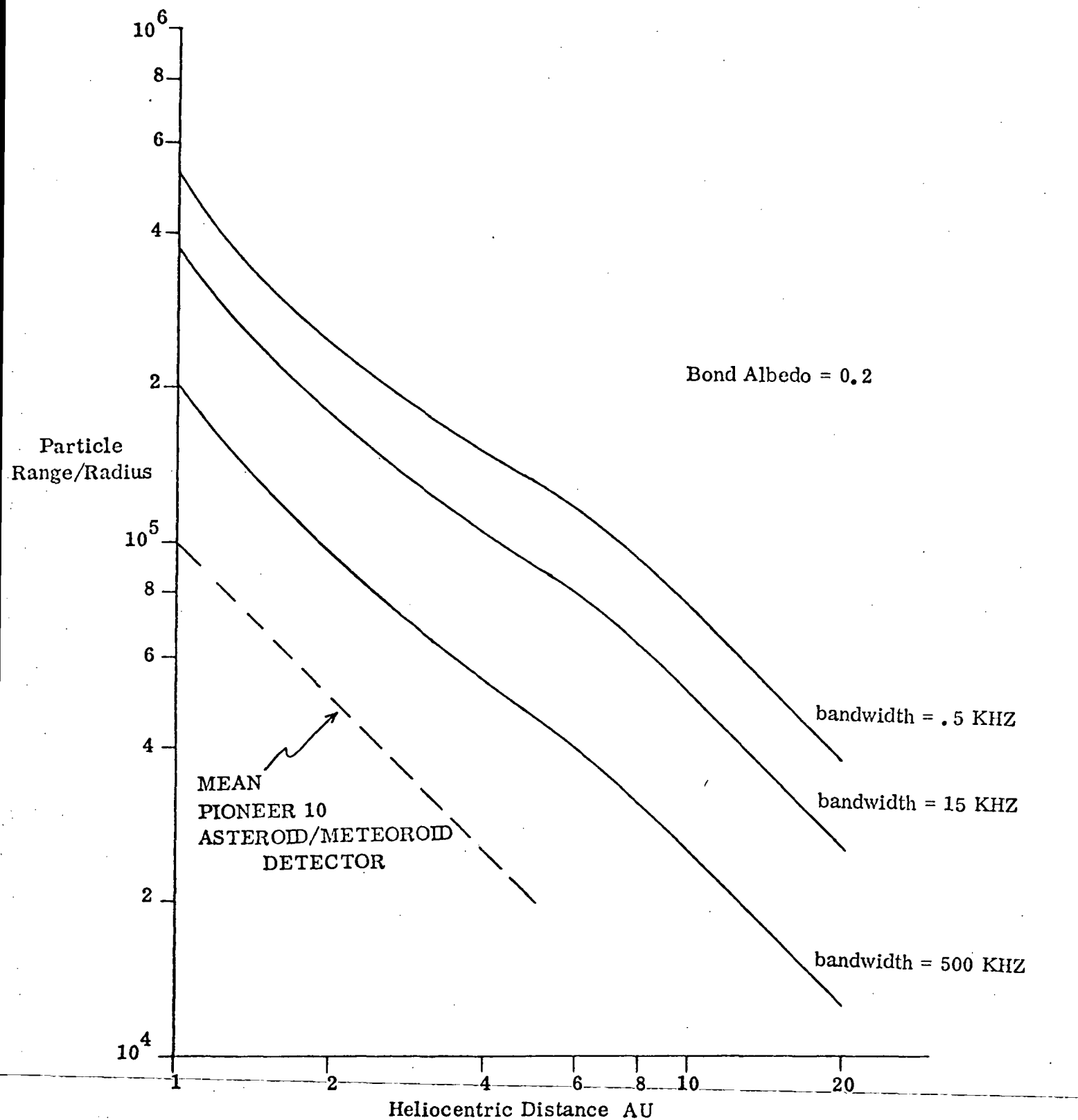


FIG. 9

Sisyphus Sensitivity vs. Heliocentric Distance for MJS '77  
Trajectory.

would necessitate longer time constants (and consequently larger components). The optimum scheme for spacecraft and instrument can be worked out with the Project.

At Saturn encounter a bit rate of approximately 50 bits per second for 20 hours ( $\pm 10$  hours of ring plane passage) in real time telemetry should be adequate for the Sisyphus instrument to characterize the individual optical particle data. No tape recorder capacity is required for Sisyphus data since the Earth and Sun occultations occur almost simultaneously at planetary encounter. The instrument will not yield remote optical sensing data during this time (applies only to Sisyphus data). The real time telemetry requirement is essential for hazard evaluation should the spacecraft malfunction after ring passage. It is again pointed out that the sample JST trajectory which crosses the ring plane in the shadow of the planet is not acceptable for Sisyphus particle measurements.

### 3. Combined Light Flash and Acoustic Microparticle Detector

One of the primary optical telescope mirrors of the Sisyphus will be instrumented for microparticle impact sensing. This is accomplished by measuring both the impact flash and the acoustic signal in the mirror in coincidence. This arrangement yields high noise immunity for the combined detector.

The combined detector will yield information about the spatial density, mass and velocity of small particulate matter as a function of solar distance. The minimum detectable mass is approximately  $10^{-12}$  grams. Addition of this detector thus extends the particle measurement range of Sisyphus. Since the mass and velocity dependence of the light flash and acoustic sensors differ, these parameters can be separated by the combined detector. At Saturn encounter, the mass of impacting ring particles can be directly obtained since the velocity relative to the spacecraft is known. Directional information is obtained as a result of the limitations imposed by the Sisyphus stray light shields which will have a  $90^\circ$  acceptance angle in the ecliptic plane. The pointing has been chosen to allow entry of asteroidal and Saturn ring particles for the sample trajectories (see Appendix H). The directional information obtained on interplanetary particulates will be combined with the directional information from the other microparticle detectors and Sisyphus.

The acoustic detector has been the subject of many papers and considerable experience has been gained with this sensor (e.g., Lindblad et al., 1970, 1972). The sensor produces an electrical signal which is related to the mass and velocity of an impacting particle. The signal is narrow band amplified and then processed in coincidence with the impact light flash signal (Figure 10). Use of coincidence circuits provides high noise immunity and substantially improves the sensitivity and reliability of the acoustic detector.

As part of the definition phase of the Outer Planets Missions, a study of the impact flash detection scheme was undertaken. The results of this study formed the subject of a dissertation (Eichhorn, 1972). Additional calibration studies with the flight telescope hardware will be carried out at the Lund Observatory and the

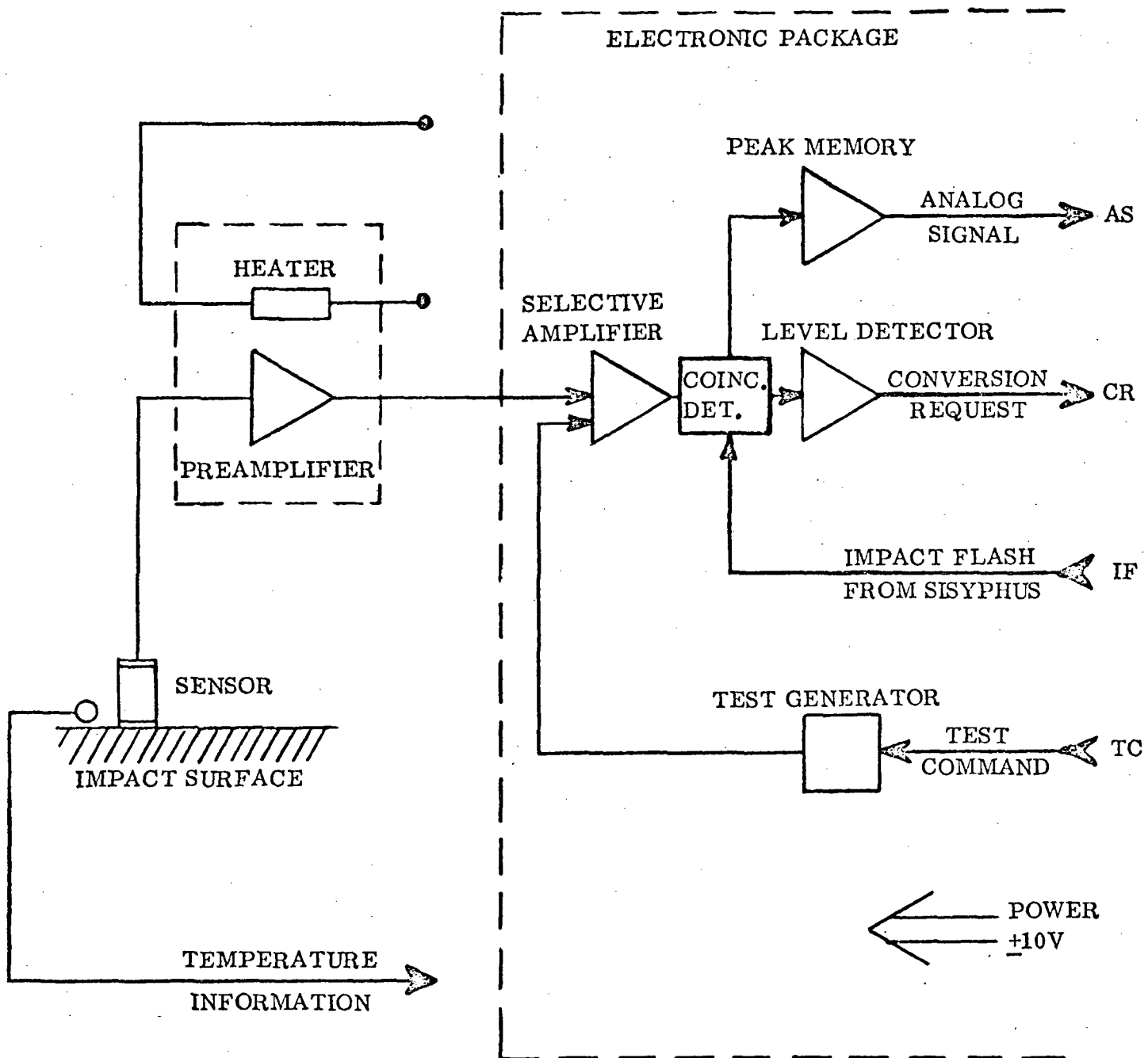


FIG. 10

SYSTEM DIAGRAM

FOR COMBINED LIGHT FLASH/ACOUSTIC  
MICROPARTICLE DETECTOR

TABLE 1

## TELESCOPE CHARACTERISTICS FOR SISYPHUS AND PHOTOPOLARIMETER

1. Sisyphus and Photopolarimetera. Optics

Type: Ritchey-Chrétien, Cassegrain

Primary: 20 cm diameter, f/1.0

Secondary Magnification: 1.1

Vertex Spacing: 10 cm

Field of View: 4° total

b. Photomultiplier

RCA 7151Q

S20 Photocathode

2. Photopolarimetera. General

Photomultiplier with fused silica end window

Field of View variable with focal plane field stop

Polarizers of Polacoat on fused silica

Temp. Control Passive, 0.7 w heater when off

b. Filter Bandpasses

<u>Position No.</u>	<u>Nominal Wavelength</u>	<u>Half-power Bandpass</u>	<u>1/λ</u>
1	2200 Å	300 Å	4.5 μ <sup>-1</sup>
2	2500	300	4.0
3	2900	300	3.4
4	3300	200	3.0
5	4000	100	2.5
6	5300	100	1.9
7	7100	200	1.4
8*	5000	~6500	-

\*Open Window for Particle Detection

c. Aperture Ensemble (Eight Positions)

- (1) Two field stops of  $4^\circ$  equipped with orthogonally oriented polarizers.
- (2) Two field stops of  $0.25^\circ$  equipped with orthogonally oriented polarizers.
- (3) Two open apertures of  $4^\circ$  and  $0.25^\circ$  respectively.
- (4) One dark position.
- (5) One calibration position.

d. Drive

- (1) Eight position stepper motor for filter wheel.
- (2) Eight position stepper motor for aperture wheel.

Max Planck Institut für Kernphysik. The placement of the acoustic sensor on the Sisyphus telescope is shown in Figure 7. The electronic block diagram is shown in Figure 10. Twenty-four data bits per event, which can be telemetered at an average rate of 0.01 bits/sec are required for this combined sensor. At Saturn encounter, 10 bits/sec in real time telemetry and on tape during occultation should suffice for ring characterization. Here, also, the real time requirement is essential for hazard evaluation should the spacecraft malfunction after ring passage.

#### 4. Photopolarimeter

As discussed above, the fourth Sisyphus telescope will be mounted on the scan platform where it is used intermittently for photopolarimetry. For this purpose it is desirable (but not essential) to be boresighted with the TV and other scan platform instruments to permit simultaneous measurements of stellar occultations, planetary and satellite surfaces and calibration stars. If this telescope is aligned with the other scan platform instruments, it can be used to photometrically calibrate the TV system, since the photopolarimeter will have a photometric accuracy of better than 1%. Problems posed by the requirement that it be aligned with the other three Sisyphus telescopes in the "normal cruise mode" are discussed below.

During the planned spacecraft roll maneuvers at 0.5 au intervals, the spectral distribution, intensity and polarization of the zodiacal light will be mapped over the sky as close to the sun as possible (consistent with light shield length and with other scan platform instrument restrictions). This mapping will require that the scan platform be stepped at approximately  $3^{\circ}$  intervals on an axis perpendicular to the roll axis. Approximately 50 rolls are required for this purpose. An additional 5 to 10 rolls are required to determine alignment errors when the telescope is re-aligned with the other Sisyphus telescopes. Relative alignment errors can also be determined from several TV sky pictures without need for additional rolls. To obtain a better determination of surface brightness of the sky as a function of solar distance and ecliptic longitude, the polarimeter should be pointed to a grid of selected areas of the sky once every week or two in addition to the full sky mapping at 0.5 au intervals.

A similar telescope and other instruments currently being used to support Pioneer and Skylab operations will be used throughout the missions at the Dudley Night-Sky Observatory atop Mt. Haleakala in Hawaii. These observations will uniquely determine the amount and optical properties of particulate light matter between the Earth and the spacecraft and, separately of particulate matter beyond the spacecraft. They will also aid in interpreting data from the flight instrument, and will measure temporal variations from the Pioneer, Skylab and HELIOS data by serving as the intercalibration reference. Parallax measurements between the ground and spacecraft instruments can confirm or deny the existence of libration clouds and the so-called "bright blobs". In addition, near simultaneous ground and deep space measurements will aid in the interpretation of past and future ground based astronomical measurements by directly determining sources and sinks of radiation, in the atmosphere, in the solar system and beyond.

From these observations, maps will be produced of the starlight and the zodiacal light. The color of the zodiacal light will be studied as a function of solar distance and elongation and compared to the sun color (Peterson, 1967). The zodiacal light measurements can then be compared with models in the manner of Gillett (1966), Giese and Dziembowski (1967) and Wolstencroft and Rose (1967) to determine the spatial concentrations and properties of the interplanetary particles. This investigation will have the advantage of the additional ILIAD data which will define parameters (e.g. particle composition, size distribution and spatial distribution) that will resolve ambiguities in previous models. The zodiacal light is expected to be faint beyond Jupiter due to the reduced solar intensity. Measurements in the outer solar system will be extremely valuable in that they will provide the first sky measurements without a significant contribution from zodiacal particle scattering. Only under these unique conditions is it possible to separate integrated starlight and diffuse galactic light and to make possible a direct measurement of cosmic light.

The flight measurements at  $\lambda = 2500$  and  $2200 \text{ \AA}$ , which cannot be duplicated on the ground, are of particular interest because recent results from OAO-2 (Lillie, 1972) suggest that large numbers of very small particles may dominate the zodiacal light at short wavelengths. Information on the polarization and spatial distribution of these particles is crucial for determining their composition and origin.

Given the appropriate spacecraft trajectories and placement on the scan platform, it will be possible to study Saturn's rings and the atmospheres of Jupiter and Saturn through stellar occultation experiments in the manner of Evans and Hubbard (1971) to determine limits on ring particle size, ring atmosphere, planetary atmospheric scale heights and cloud-top heights.

If the photopolarimeter is boresighted with the TV it will be possible to perform polarimetric studies of the atmospheres of Jupiter and Saturn and the surfaces of their satellites.

The instrumentation for this portion of the integrated investigation is basically a large aperture, multipurpose photometer (see Figure 11). Light is collected by the same 8-inch Ritchey-Chrétien version of a Cassegrain telescope whose specifications are listed in Table 1. At the focal plane of the telescope there is an aperture wheel equipped with sets of  $4^\circ$  and  $0.25^\circ$  field stops; both sets of field stops are equipped with orthogonally oriented polarizers and an open aperture. Dark slide and calibration positions are also provided. A filter wheel is located directly behind the aperture wheel and is equipped with seven bandpass filters and an open aperture. Both wheels with filter passbands are shown in Figure 12. Each wheel is driven by an 8-position stepper motor and can be driven to any position, or run in any of several modes by a 12-bit command.

The detector is an end-window photomultiplier tube with S-20 photocathode response (RCA 7151Q) located directly behind the filter wheel. The output signal at the anode provides analog data for individual particle detection and pulse-count data for zodiacal light measurements. The data can be high or low, either 20 bits/sec or a 20-bit word every 64 seconds. A data word consists of a 14-bit (15 bits known) compressed data



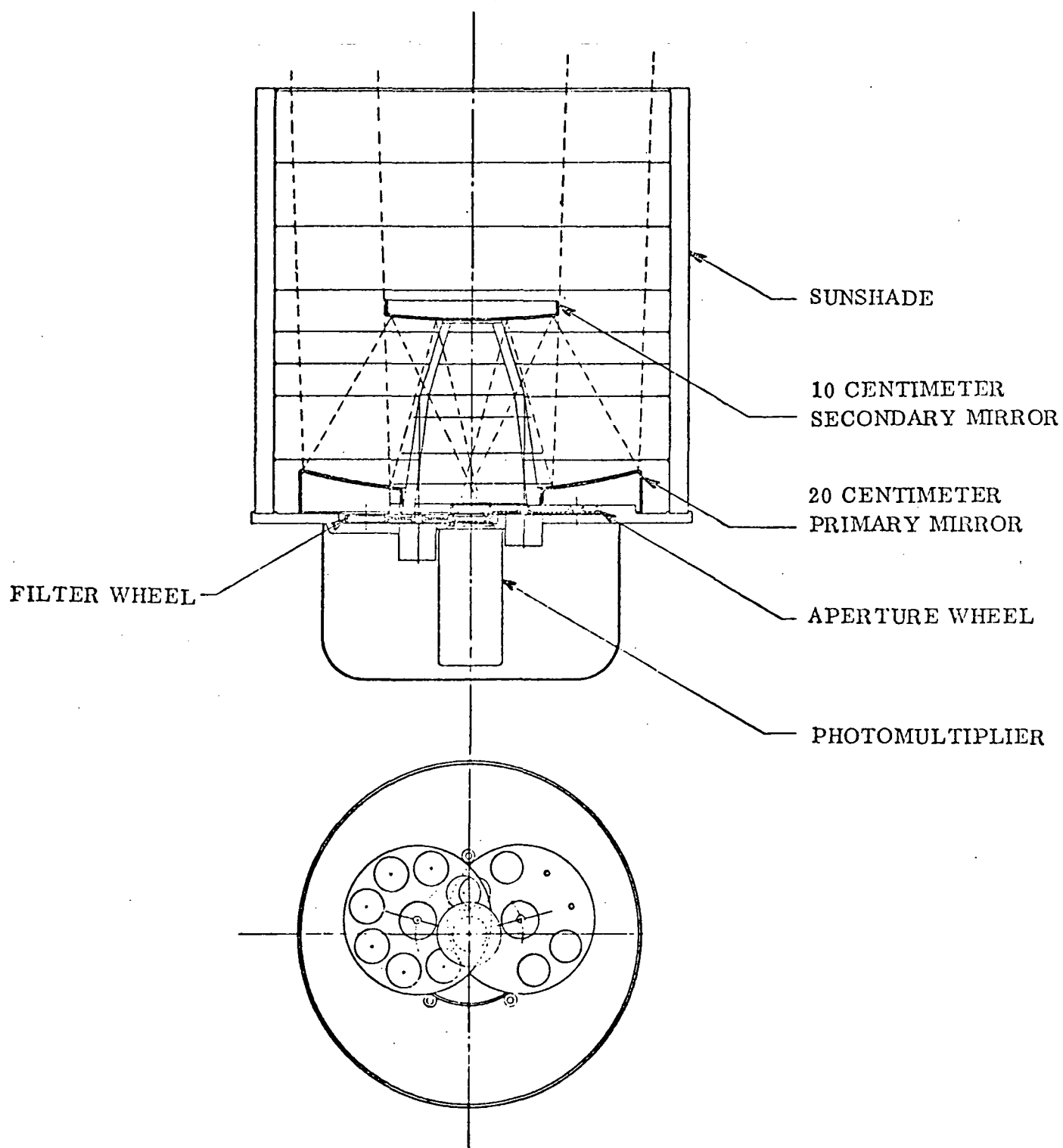


FIG. 11

PHOTOPOLARIMETER  
OPTICS AND FILTER WHEEL

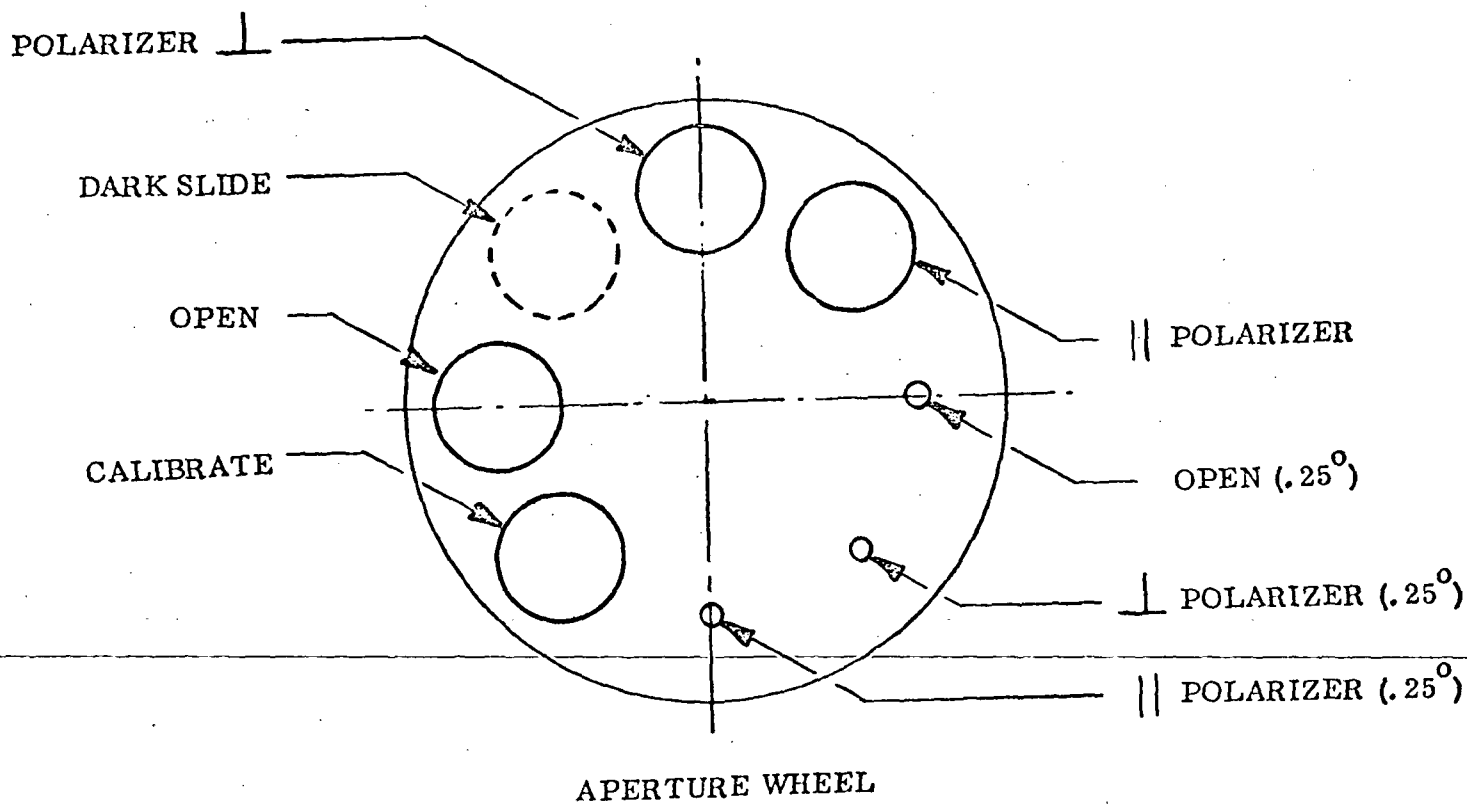
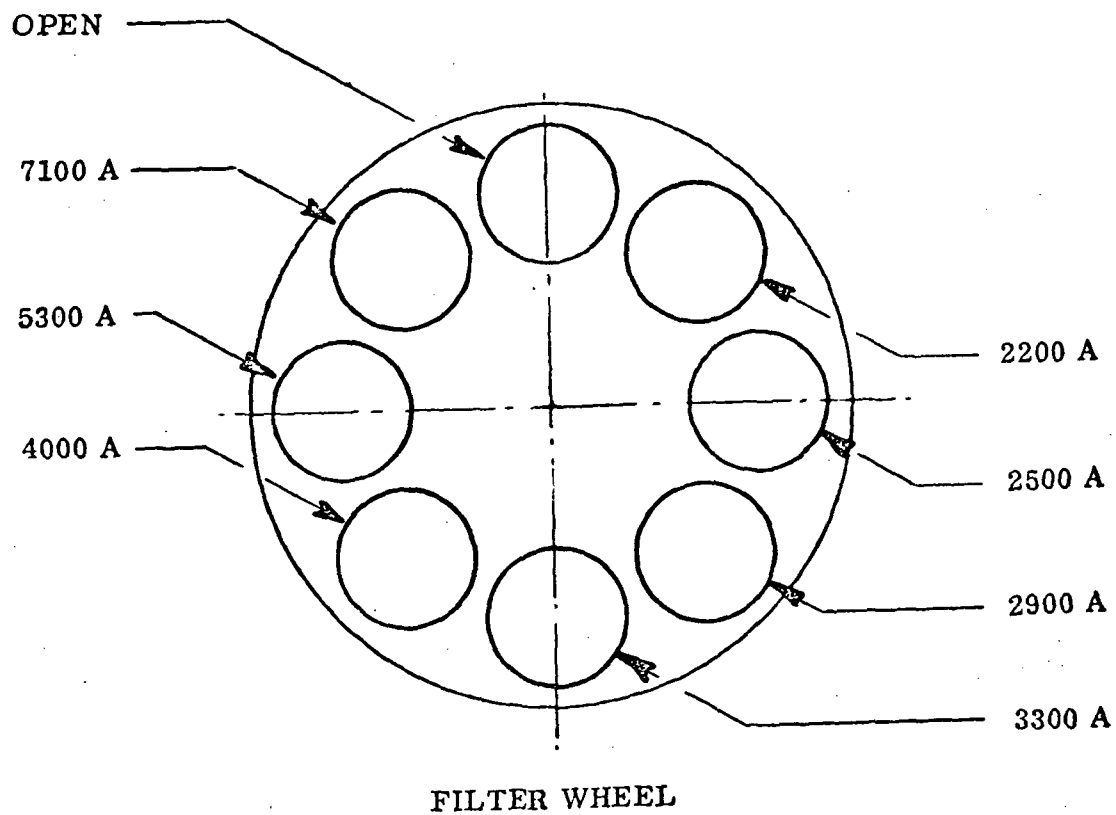


FIG. 12

PHOTOPOLARIMETER FOR MJS '77

readout, 4 bits for filter and aperture wheel positions, one bit overflow time flag, and one bit spare. A block diagram of the electronics is shown in Figure 13.

The photomultiplier and telescope will be similar to those used on Pioneer 10/G. The four UV filters will be equivalent to those used on OAO-2 and the three filters for the visible and near IR will be equivalent to those used at Haleakala and on Skylab. Stepper motors will be of the type used on OSO-I and similar to those used on Mariner 9.

As shown in Figures 4 and 5, the preferred position is on the spacecraft scan platform boresighted with the TV. Other arrangements are possible. In the cruise mode it should be positioned with the optic axis within  $20'$  ( $\sim 6$  mr) of the optical axis of Sisyphus. Alignment calibration was discussed above. While it is true that the cruise mode pointing is chosen to allow asteroid impacts on one Sisyphus mirror (see Appendix H), measures for protecting the other optical instruments from such impacts will be defined from Pioneer 10 data by 1973. Several schemes to afford protection for scan platform instruments appear feasible and it should be remembered that the microparticle instrumentation proposed herein should give adequate warning to redirect the scan platform if a particle impact problem appears likely (i.e., increasing flux). For most optical instruments the small number of microcraters that can be expected are negligible compared to manufacturing flaws (Zook et al., 1970). The concern with accidentally pointing the scan platform instruments at the sun in the event of a loss of spacecraft stabilization can be treated by making provision for slewing the scan platform to a protected position at the loss of sun and/or Canopus references. The spacecraft tumble rate would be slow enough for an on-board procedure to slew the scan platform to point at the antenna before the sun enters the field of view of any of the instruments.

## 5. Synergistic Measurements

From the foregoing it can be seen how individual sensors of the combined investigation are directed to the scientific objectives. It remains to be shown how the combined data can yield information which cannot be obtained from the sensors individually. As has been pointed out earlier, the dynamic ranges of the sensors overlap each other. Characteristic velocity data from the nearly omnidirectional Sisyphus will be used with the data from the microparticle impact detectors to better determine particle masses. The mass distribution data from the microparticle detectors will be fitted to the size distribution from Sisyphus to form a continuum. This determines a mean particle density and albedo. From the integrated light measurements parallel to the spacecraft velocity vector, the total amount of scattered light contributed by particulate matter will be determined as a function of distance along the flight path. Since this should be equal to the integral over the size distribution times a mean albedo, the mean albedo can also be inferred in this manner. This must also be in agreement with the scattering angle dependence determined by the zodiacal light measurements and with the refractive index of the particles which can be inferred from their composition and spectral scattering characteristics.

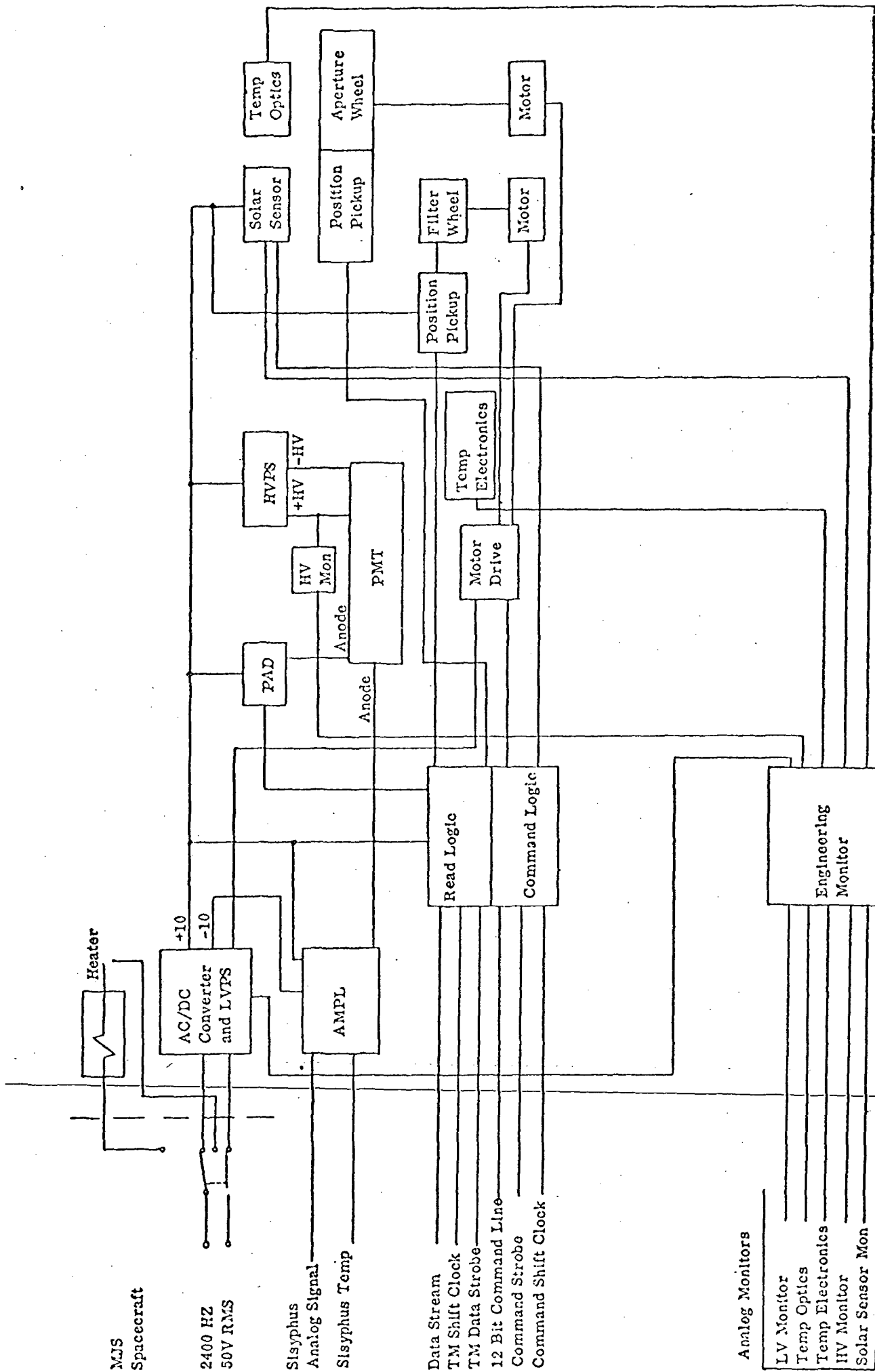


FIG. 13  
PHOTOPOLARIMETER SYSTEM DESIGN

At Saturn the data from the ILIAD in situ and remote detectors will be combined to characterize the composition and physical nature of the ring particles. It is anticipated that remote infra-red, ultra-violet and radio occultation data will also be available from other instruments on the spacecraft. The thermal characteristics of the particles (from the IR) and the ring atmospheric density and composition (from the UV and Radio Science) can be combined with the ILIAD data to completely determine the nature of the rings and their interaction with the planetary, satellite and solar system environment.

TABLE 2

## INSTRUMENT SUMMARY

	<u>MIA</u> <sup>1</sup>	<u>Sisyphus</u> <sup>2</sup>	<u>Photopolarimeter</u>	<u>Total</u>
Weight (Kg)				
Sensors	0.8	2.0	} 1.6	7.4
Electronics	1.7	1.3		
Dimensions (cm)				
Sensors	40 x 40 x 120	50 x 50 x 30	} cylindrical, 23 dia. x 30 length	-
Electronics	20 x 20 x 10	15 x 15 x 8		
Power (w avg.)				
Sensors	0.1	0.9	} 0.7	6.3
Electronics	2.5	2.1		
Telemetry (bits/sec)				
Avg.	0.5	0.5	0.3	1.3
Max.	50	50	20	120.
Thermal Controls	Passive	Passive	Passive when on, 0.7 w when off	-
Deployment Mechanisms	None	None	None	-
Field of View	-	4°	4° Max.	-
Acceptance Angle	3 x 120°	90°	-	-

Note: 1 Microparticle Ionization Analyzer

2 Included with Sisyphus is the Combined Light Flash and Acoustic Microparticle Detector

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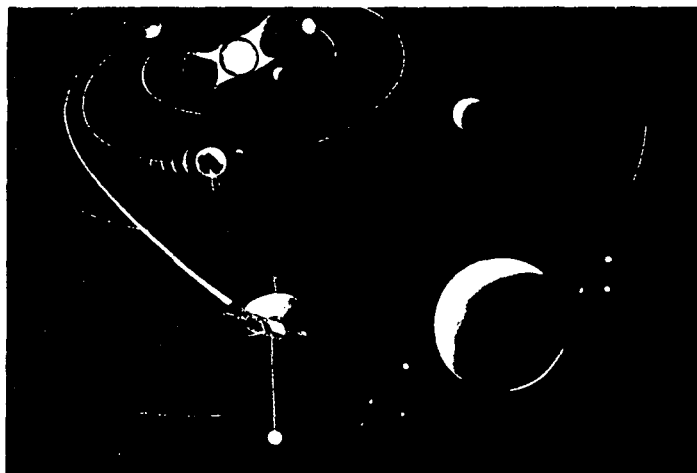


## **APPENDIX A**



**the 17th ANNUAL MEETING**

**THE OUTER SOLAR SYSTEM**



PREPRINT NO. AAS-71-127

# **COMBINED ZODIACAL EXPERIMENT**

Robert K. Soberman

**June 28-30, 1971**

**Washington Plaza Hotel  
Seattle, Washington**

## COMBINED ZODIACAL EXPERIMENT\*

Robert K. Soberman+

The proposed Combined Zodiacal Experiment on the Outer Planets Missions will include the study of the distribution and orbits of meteoric, asteroidal and satellite particles using an optical detection system (Sisyphus) with four lightweight 40 cm aperture telescopes. These telescopes will also be utilized for studies of the brightness and polarization of the zodiacal light and sky background in two colors. The primary mirrors will also act as impact surfaces for micrometeoroid distribution, mass, energy, composition and velocity studies. Coincidence sensors measure both the ionization and light flash produced upon impact, thus, reducing the noise susceptibility over that of either technique utilized along. Thought is being given to analyzing the ionization pulse by the "time-of-flight" technique to derive information about the composition of the impacting particle. The combined measurement is keyed to the search for primordial particulate matter which has been predicted to be in orbit about the sun and outer planets. The experiment should also obtain the first direct measurements of interstellar grains and will make possible direct measurements of diffuse galactic light (integrated starlight scattered by interstellar grains) and cosmic light (integrated light from extra-galactic sources). The experiment will not only uniquely establish the nature and bounds of the interplanetary particulate medium, but in those regions where concentrations of such material are not encountered, the extremely valuable interstellar and extra-galactic astronomical measurements of the combined sensors will be enhanced.

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\* Prepared for technical papers that will later be published in the Proceedings of the American Astronautical Society.

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## SCIENTIFIC OBJECTIVES

The primary objective of the Combined Zodiacal Experiment is to shed new light on the origin of the solar system through an extensive study of the primordial and evolving particulate matter and its dynamic interactions with solar and planetary forces. Primary emphasis is placed on the dramatic transitions that are expected to occur in the concentration of such material as one passes beyond the orbit of Jupiter. Although many questions remain regarding the zodiacal complex inside the orbit of Jupiter, terrestrial and near-earth studies have enabled us to establish limits on the nature and dynamics of meteoric material that resides or transits inside this boundary. What lies beyond the so-called "Jupiter Trap" is still, however, a complete mystery. Theories regarding the effectiveness of Jupiter in sweeping up meteoric material attempting to cross its orbit come to diametrically opposed conclusions<sup>1,2</sup>. One point, however, is clear from the various theories -- particles of different size would be affected quite differently. While very small micrometeoroids should be able to penetrate the Jupiter barrier with little difficulty, particles in the millimeter to several centimeter size range, moving in circular orbits gradually being degraded by the Poynting-Robertson effect, should be prevented from coming closer to the sun. Still larger particles are very little affected by solar radiation and, consequently, should be moving in approximations of their original orbits. If the particles are constantly evolving from long period comets and are, like the parent bodies, moving in highly elliptic orbits, then the Jupiter perturbation is more likely to throw them out of the solar system. If, on the other hand, there is a large amount of primordial material moving in orbits similar to the planets, then the difference in concentration should be large. It has been recently shown<sup>3</sup> that a cometary origin cannot be hypothesized for the interplanetary material which produces the gegenschein. This material must originate in the asteroid belt or beyond. Only simultaneous investigations of the radial distribution of small (<100 microns) and large particles, together with the integrated light scattered from these particles, can resolve such questions.

The search for primordial particulate matter is thus a major objective of this investigation. Within 5 au, cometary and meteoric studies show that most bodies have been influenced by the Jovian gravitational field. Beyond Jupiter, one is likely to find material in relatively undisturbed primordial orbits. The evidence of the Asteroids and the Trojans strongly suggests that there may be similar concentrations of minor bodies farther out from the sun where they are unlikely to be detected by terrestrial telescopes. One can make the same comment with respect to evidence of comets which have large perihelia ( $>5$  au). Zodiacal particle investigations could well give additional information about the numbers of such comets.

The Jupiter Trap is a specific (and the most pronounced) example of the planetary sweeping effect predicted by Öpik<sup>2</sup>. This theory has, however, never been properly tested. The planetary sweeping effect (if valid) is important in determining planetary accretion or loss of mass. The local meteoric flux is especially important in the case of Saturn. According to Cook and Franklin<sup>4</sup>, the meteoroidal bombardment is the primary determining factor for the stability of Saturn's rings.

Another hypothesis put forth<sup>5</sup> that remains to be tested is that the outer planets have concentrations of particulate material in orbit about their gravitational center. Only in the case of Saturn are these concentrations large enough to be visible to terrestrial telescopes. A test of this hypothesis obviously has important scientific value, as well as an important bearing upon the success of the Grand Tour Mission.

The surface age of bodies in the solar system having rarefied atmospheres can be estimated by observing the crater size distribution and correlating it with the local meteoroid flux as a function of particle size and velocity. During the Grand Tour missions, the proposed experiment should acquire sufficient data to make a statistically significant determination of the flux as a function of meteoroid size and mass. Since the proposed detectors also measure the velocities of the particles, the energy distribution of larger bodies impacting the planets can be derived. Thus, if one also obtains video information about the surface of the planets,

the proposed experiment, in conjunction with this video information, will yield valuable results for determining mass history, surface condition and history, atmospheric history, and surface composition of those planets with no appreciable atmosphere.

The spatial distribution and extent of interplanetary particulate material will be obtained directly from the zodiacal light studies. Measurement of brightness and polarization in two colors will show any changes in size distribution and chemical composition as one moves away from the sun. Only in these missions is it possible, by measurement of the integrated sky brightness, to obtain direct information on the spatial distribution and extent of interplanetary particulate matter. Even if interplanetary particulate concentrations remain high, the zodiacal light should diminish at large heliocentric distance due to the fall-off in sunlight. This will make diffuse galactic light (integrated starlight scattered by interstellar grains) and cosmic light (integrated light from extra-galactic sources) more amenable to measurement.

Finally, the range of sensitivity of the ionization-impact flash detector offers the possibility of direct measurements of interstellar grains. At large heliocentric distances, it should be easier to distinguish these grains from interplanetary particles and measure their concentration, mass, composition and velocity.

#### INSTRUMENTATION DESCRIPTION

The integrated instrumentation proposed for the Combined Zodiacal Experiment consists of a remote optical meteoroid-asteroid detector (Sisyphus), an ionization-impact flash micrometeoroid detector, and a zodiacal light-sky background measurement system. The resulting experiment provides a synergistic effect in that parameters can be measured by the combination that cannot be determined by any one of the detectors alone. These include orbital parameters (velocity, eccentricity, inclination, etc.), mass, size and derived quantities such as momentum, energy, particle concentration, and scattering properties. Further, the integration allows significant noise rejection by requiring coincidence between detectors.

### Sisyphus

Sisyphus is an optical instrument designed primarily to make measurements of small interplanetary particles which pass within several kilometers of the spacecraft. As it is an optical system, it can also detect larger bodies at greater distances. The amount of light incident upon the instrument resulting from an assumed spherical object can be approximated by

$$I = \frac{I_o r \pi a^2}{2 s^2 \pi R^2} = \frac{I_o r}{2 s^2} \left[ \frac{a}{R} \right]^2 \quad (1)$$

where  $I_o$  is the solar irradiance at one au;  $r$  is the reflectivity of the object (equal to 3/2 times the "geometric albedo");  $a$  is the radius of the object;  $R$  is the range from the object to the detector; and  $s$  is the distance from the sun in astronomical units. A sun-object-instrument angle of approximately  $45^\circ$  is assumed. For a single detector, one would have no way of distinguishing objects with the same  $a/R$  ratio. The Sisyphus concept provides a means of determining the range and, hence, the size of the object.

Consider three optically aligned telescopes equipped with photomultipliers as defining three parallel cones in space. If the telescopes are identical, then the edges of the fields of view remain at a fixed distance from each other regardless of range. Any luminous object which crosses through the intersecting fields of view is then detected by each of the photomultipliers. From the entrance and exit times in each field of view, one can completely calculate the trajectory of the object in space, provided only that one has sufficiently good optics and a sufficiently long baseline between telescopes.

For the mathematics of the system, we define three cones with half angles  $\theta$  as shown in Fig. 1. Lines joining their apexes form an arbitrary triangle in the plane perpendicular to their axes. For purposes of convention, the vector from the base of the  $i^{\text{th}}$  cone to the particle's entrance into that cone is designated  $\vec{\rho}_i$  and the vector to the particle's exit is  $\vec{\sigma}_i$ . Times of entrance and exit at the  $i^{\text{th}}$  cone are designated  $\tau_{ij}$  where  $j$  is 1 for an entrance point or 2 for an exit point.  $\vec{V}$  is an arbitrary velocity vector.

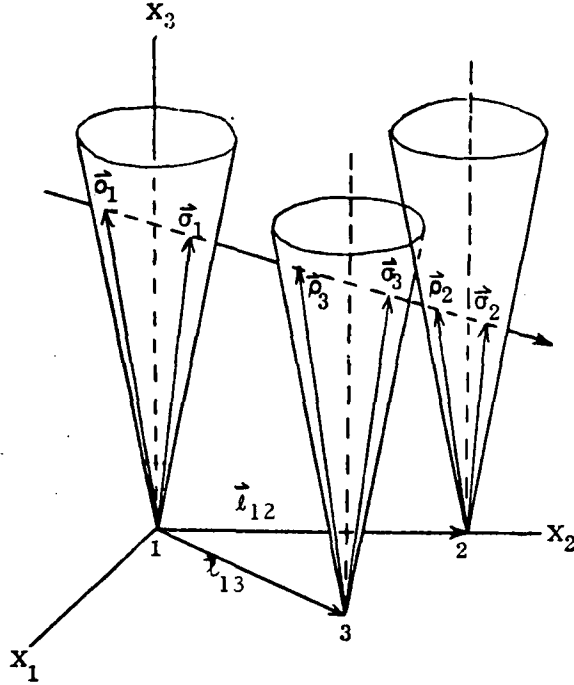


Fig. 1 Sisyphus Geometry (for convention only)

Using this convention, five independent vector equations result:

$$\begin{aligned}
 \vec{\sigma}_1 &= \vec{\rho}_1 + (\tau_{12} - \tau_{11}) \vec{V} \\
 \vec{\rho}_2 &= \vec{\rho}_1 + (\tau_{21} - \tau_{11}) \vec{V} - \vec{\ell}_{12} \\
 \vec{\sigma}_2 &= \vec{\rho}_1 + (\tau_{22} - \tau_{11}) \vec{V} - \vec{\ell}_{12} \\
 \vec{\rho}_3 &= \vec{\rho}_1 + (\tau_{31} - \tau_{11}) \vec{V} - \vec{\ell}_{13} \\
 \vec{\sigma}_3 &= \vec{\rho}_1 + (\tau_{32} - \tau_{11}) \vec{V} - \vec{\ell}_{13}
 \end{aligned} \tag{2}$$

By breaking these into components, we have 15 equations in 15 unknowns so a solution exists. Since the derivation is long and tedious, it is omitted here. The solution has been programmed for computer use.

The above vector equations remain unchanged if the cone axes are misaligned (i. e., not parallel). However, the 15 component equations are more complex since they involve two additional angles for each cone necessary to specify its orientation. This misaligned case has been reduced from the 15 original equa-



tions to three equations in three unknowns. Because of their complexity, further reduction appears impractical. Numerical solutions are obtained by computer iteration.

Thus, independent of the amplitude of the signals detected by the individual optical systems, one can establish the three velocity components and the range of the body. Using this calculated range, the measured light intensity at the detector and the known solar intensity, one can solve Eq. (1) for the product of the reflectivity and the cross-sectional area, and thus determine the mean radius of the body to an uncertainty of the square root of the reflectivity. Further, from the real time at which the event took place, the known position, velocity, and orientation of the vehicle from which the measurement was made, and the three velocity components of the body, the complete orbit of the body in the solar system can be determined.

The proposed configuration is specifically designed to: (a) compensate for the reduced sunlight at large heliocentric distances, (b) take maximum advantage of the design of the TOPS vehicle, and (c) provide maximum reliability for the lengthy Grand Tour missions. It was shown above that three properly arranged optical telescopes yield all of the data required for the Sisyphus concept. Since, to a large extent, these telescopes operate independently, the addition of a fourth adds more than 20% in overall reliability and a factor of two in data accuracy. Further, the output of each of these telescopes will be put through multiple electronic logic channels of differing bandwidths. This subdivision of signal serves the two-fold purpose of adding reliability (in the event that a channel fails) and providing a wide dynamic range of signal sensitivity. To compensate for the decreased solar intensity, the aperture of the individual telescopes will be doubled over the 20 cm size being utilized on Pioneer F/G. Additional sensitivity is gained by taking advantage of the three-axis stabilization of the TOPS vehicle. The instrument orientation will be fixed with respect to the spacecraft and will be selected to minimize the star background (and, consequently, the photon noise which is a limiting factor to the Sisyphus instrument). It is fortunate that one can achieve this background and noise reduction while still maintaining a

reasonable (approximately  $30^\circ$ ) angle with the ecliptic for impact detection of micrometeoroids. Two additional significant changes are made from the Pioneer version; the first is a change in the photomultiplier tube type to permit use of an end window which will not darken in the anticipated Jovian radiation environment. The other change is in the logic components from COSMOS to TTL for radiation hardening.

The instrument sensitivity in terms of range-to-radius ratio as a function of heliocentric distance and particle reflectivity is shown in Fig. 2. It is compared with the present Pioneer F/G version of the instrument. The minimum detectable particle radius would only increase from a value of about 10 microns at 1 au to about 350 microns at 30 au. While there will be increased event sensitivity at the narrower bandwidths, there is a resulting loss of accuracy in some of the velocity data. Size (subject to the uncertainties of albedo or reflectivity) and angular velocity will be determined for all particles detected, but linear velocities will be determined only for some. Unlike an impact detector, the sensitivity of the optical detector improves with reduced particle velocity. It should be noted that the velocity of the meteoric material is expected to decrease substantially as one moves away from the sun. For example, at 30 au, the maximum encounter velocity anticipated for a Grand Tour type of mission will be 15 km/sec (opposed parabolic orbits). This is an upper limit and encounter velocities

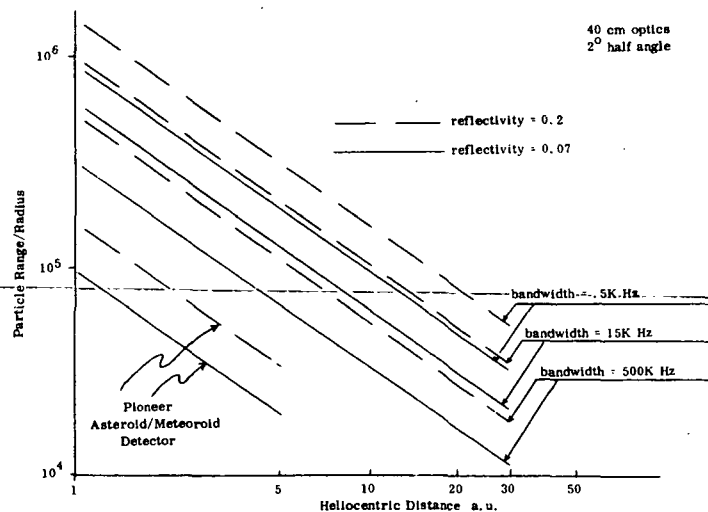


Fig. 2 Sensitivity vs. Heliocentric Distance  
for Proposed Grand Tour Sisyphus Instrument

of less than 9 km/sec are more likely. Within these limits, it is anticipated that full velocity information will be determined for approximately 20% of the events detected at 1 au, 40% at 10 au, and about 50% at 30 au.

### Zodiacal Light and Sky Background

Zodiacal light and sky background will be measured with the same four telescopes. Red and blue contributions, as well as the two orthogonally polarized components, will be determined. Each telescope measures one polarized component of one color, thus avoiding the need for moving parts. Since this discrimination is incompatible with the Sisyphus detector which requires maximum light input, separate photomultiplier tubes are used slightly off axis for the zodiacal light-sky background measurements. The off-axis placement of the photomultiplier tube results in a slightly distorted field of view which differs from that of the Sisyphus detector (see Fig. 3). Especially important are the measurements made during the 0.5 au rotations of the TOPS vehicle. Proper alignment of the off-axis photomultipliers with respect to the spin axis of the vehicle permits a comparison of the monochromatic measurements with the white light measurements of Sisyphus over the same region of sky.

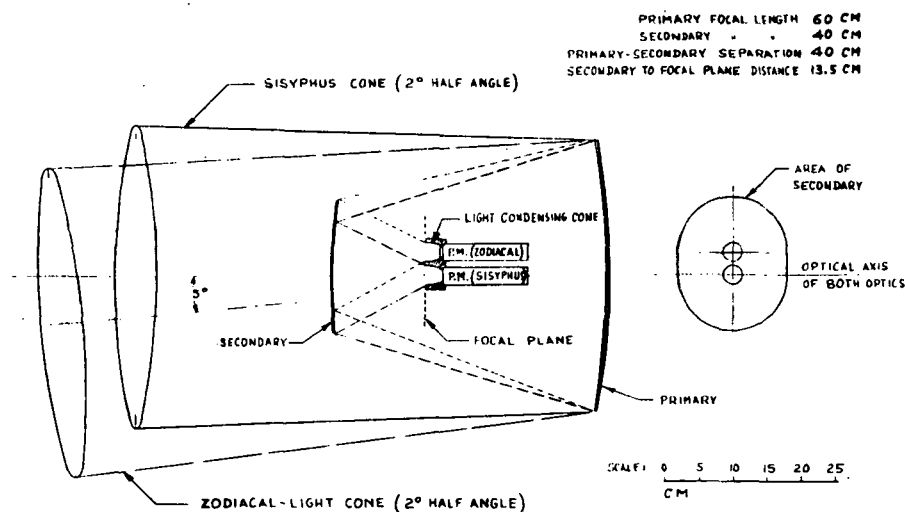


Fig. 3 40 CM Diameter F/1 System

This portion of the experiment will be capable of measuring changes in the light level of the order of several percent. The zodiacal light is expected to be faint beyond Jupiter and it is possible that there may be no measurable contributions

near or beyond Saturn if the only meteoric material there is that which originates from long period comets. Measurements beyond this point, however, will be extremely valuable in that they will provide the first sky background measurements without a significant contribution from zodiacal particle scattering. Only in this region is it possible to separate integrated starlight and diffuse galactic light and to make possible a direct measurement of cosmic light. The proposed telescopes are ideally suited to these latter measurements because of their sensitivity and relatively wide viewing field. If one does encounter concentrations of particulate matter in the outer regions of the solar system, the integrated scattered light intensity measurements obtained from this portion of the experiment will add considerably to the data obtained from the other parts of the Combined Zodiacal Experiment.

#### Micrometeoroid Ionization and Impact Flash

The concept of the impact ionization micrometeoroid detection technique has been described in the literature<sup>6</sup>. Such detectors have been flown on rockets and satellites. The impacting area (and anode) for the ionization micrometeoroid detector will be two of the four primary telescope mirrors. The optical/impact surface is composed of electro-deposited gold, which has a relatively low thermionic work function ( $\sim 4$  ev), thus providing a high ionization yield on impact. The cathode will be a ring element situated as shown in Fig. 4. This configuration yields the most uniform electrostatic field between the anode and cathode while minimizing the field distortions and optical obscurations due to the presence of an electrostatic shield ( $> 90\%$  optical transmission) over the telescope. Around the telescope, the electrostatic shield is incorporated into the lightweight optical shield required to reduce the light scattered from the vehicle to a level commensurate with the sky background. An attempt will be made to perform "time-of-flight" analysis on the ionization pulse to derive limited data on the composition of the impacting particle. Some hardware redesign will probably be required to accomplish this objective.

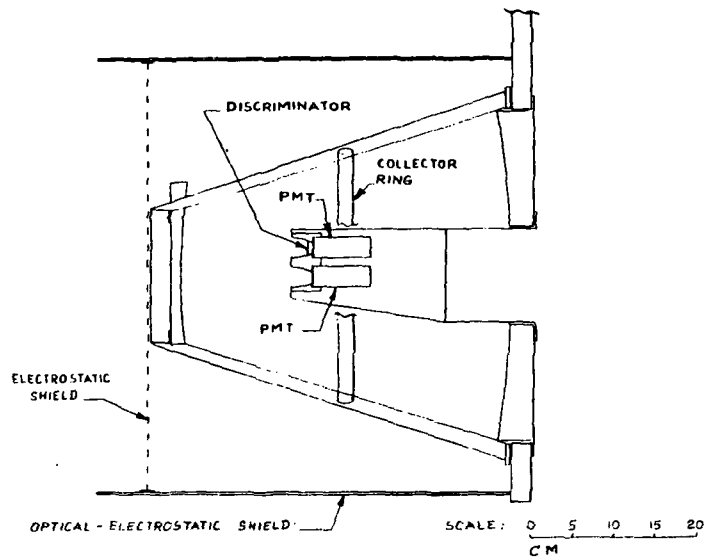


Fig. 4 Completely Instrumented Telescope

When a particle strikes the primary mirrors, it will emit a light flash. This flash will be detected by both photomultiplier tubes in the telescope. The two telescopes instrumented with the ionization detector will have different color filters for the zodiacal light-sky background sensors. By requiring coincidence between the signals from the two optical sensors and the ionization sensor, noise inherent to the two types of detection will be rejected. Thus, for each impact, one gains additional information to specify the mass and velocity of the impacting particle, as well as limited spectral information on the flash. Studies of hypervelocity iron particles impacting gold have shown that both ionization and impact flash detection are proportional to  $MV^3$ . Preliminary work has shown that the sensitivities of the two micrometeoroid impact detectors can be made to coincide (see Fig. 5).

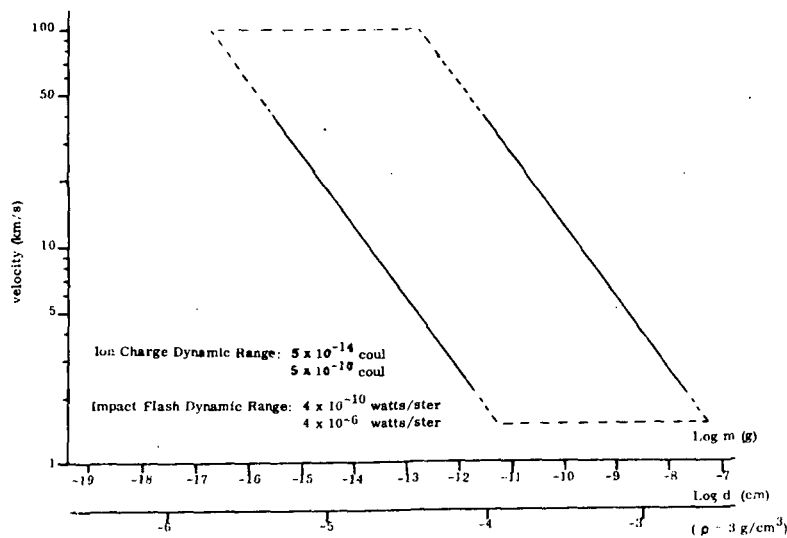


Fig. 5 Sensitivity of the Ionization and Impact Flash Detectors for Proposed Grand Tour Sisyphus Instrument

Apart from the search for circular orbit particles, the ionization-impact flash detector should also be capable of measuring interstellar grains. These grains have been predicted<sup>7</sup> to have a mass of approximately  $10^{-14} \text{ gm}^6$ , and should have a mean velocity of approximately 20 km/sec (the velocity of the sun in the galaxy). One value<sup>7</sup> for the concentration of these interstellar grains is  $2 \times 10^{-13} \text{ cm}^{-3}$ . A more recent estimate for Greenberg<sup>8</sup> gives a value for the concentration which is one order of magnitude larger. Using the more conservative estimate still would give an event rate (to a first approximation independent of heliocentric distance) of 70 per day. Reduced radiation pressure and meteoric flux will make these interstellar grains more amenable to direct measurement at large heliocentric distance.

As was mentioned above, the telescopes will periodically generate a sky brightness map. This information can reveal unusually high concentrations of particulate matter in the direction of vehicle motion at distances up to millions of kilometers. With the experience of in situ measurements by the combined sensors, potential hazard can be predicted in time to maneuver the vehicle around such regions.

## ACKNOWLEDGEMENT

The members of the definition team for the Combined Zodiacal Experiment are:

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## APPENDIX B

# GENERAL ELECTRIC

MISSILE AND SPACE DIVISION  
PHILADELPHIA

## PROGRAM INFORMATION REQUEST/RELEASE

CLASS. LTR.	OPERATION	PROGRAM	SEQUENCE NO.	REV. LTR.
PIR NO.	2R30		38	
*USE "C" FOR CLASSIFIED AND "U" FOR UNCLASSIFIED				

FROM Mr. Sherman L. Neste Room L9543	TO Dr. R. K. Soberman M9509
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DATE SENT 8/26/71	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
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SUBJECT  
OPTICAL TRANSMISSION OF A HONEYCOMB PANEL AND ITS EFFECTIVENESS AS A PARTICLE IMPACT SURFACE

INFORMATION REQUESTED/RELEASED

A preliminary design which integrates the Impact Ionization Detector with the Sisyphus Optical Meteoroid Detector utilizes a honeycomb panel placed in front of the telescope aperture as the impact surface for micrometeoroids. Obviously, this panel will reduce the amount of light which is incident on the mirror. Therefore, a computer program (TRANS) has been written which calculates the optical transmission for such a configuration. In addition, TRANS also determines the effectiveness of the honeycomb panel as an impact surface for micrometeoroids. The method of computation is detailed below.

The hexagonal cells of the honeycomb panel are approximated by right circular cylinders and the optical transmission is computed for each cell in the array as a function of incident light angle. The spatial density of cells is, however, assumed to be that which would be obtained for the actual hexagonal cells. The transmission for a given cell is then given by the ratio of unobscured cross-sectional area to total cross-sectional area of the cell (see Figure 1). By using the ratio of areas in calculating the transmission, the variation of effective area with angle (i. e.  $\cos \theta$  effect) need not be considered.

The unobscured area can be approximated as the section of a circle as shown in Figure 2. The area of Section A is given by

$$A = \frac{\pi r^2}{2} - \left( x \sqrt{r^2 - x^2} + r^2 \sin^{-1} \left( \frac{x}{r} \right) \right) \quad (1)$$

where  $r$  is the radius of the circle (i. e. cell radius) and  $x$  (equation 2) is the distance from the center of the circle to the chord which defines the section.

$$x = \frac{L}{2} \tan \theta, \quad L \equiv \text{cell length} \quad (2)$$

The total unobscured area of a cell will then be  $A + B = 2A$  and the percent transmission for each cell is given by

PAGE NO.  1 OF 6	RETENTION REQUIREMENTS	
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$$\% \text{ transmission (cell)} = \frac{2A}{\pi r^2} \quad (3)$$

Since the obscuration will be greatest for light rays originating at the edge of the field of view, the total transmission is calculated for such a configuration. The method of calculating the angle of incidence for an arbitrary cell is illustrated in Figure 3. The spatial density and total number of cells is, of course, determined by the individual cell diameter. The percent transmission for the entire panel is thus given by

$$\begin{aligned} \% \text{ transmission (panel)} &= \frac{\text{total unobscured area}}{\text{total area of panel}} \times 100 \\ &= \frac{\sum_{mn} A_{MN}}{\pi r^2 \times (\text{no. of cell/panel})} \times 100 \end{aligned}$$

where  $A_{MN}$  is the unobscured area of the MNth cell.

The effectiveness of the panel as an impact surface is determined by calculating the opacity of a typical cell as a function of particle impact angle. Therefore, we now calculate the ratio of obscured cross-sectional area to total cross-sectional area. A procedure similar to that employed in determining the optical transmission yields the following result.

$$\% \text{ impacts} = \left[ 1 - \frac{\sum_{i=1}^N A_i (\theta_i + \Delta \theta)}{NA} \right] \times 100, \quad N = \pi/2/\Delta \theta \quad (5)$$

where  $A(\theta)$  is the unobscured cross-sectional cell area (for incident angle  $\theta$ ) and  $A$  is the total cross-sectional cell area.

It should be noted that for  $\theta \geq \cot^{-1} L/D$  all of the particles intercepting the plane of the panel will strike the panel.

The percentage of optical transmission and the percentage of particle impacts can now be calculated as a function of cell length ( $L$ ) and cell diameter ( $D$ ) to determine the ratio ( $L/D$ ) which provides acceptable values for these quantities. The variation of optical transmission with range can also be investigated.

The computer program TRANS together with the plotted results of several calculations is attached.

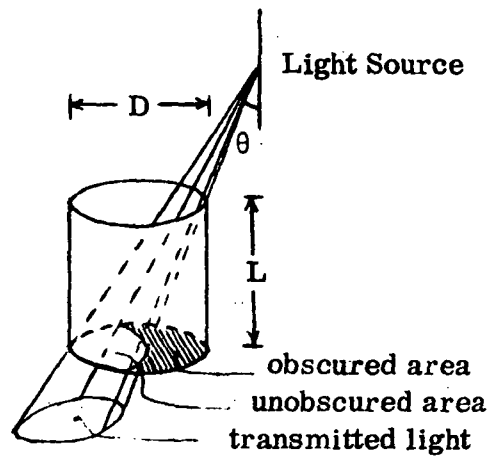


Figure 1. Optical Transmission for a Typical Honeycomb Cell.

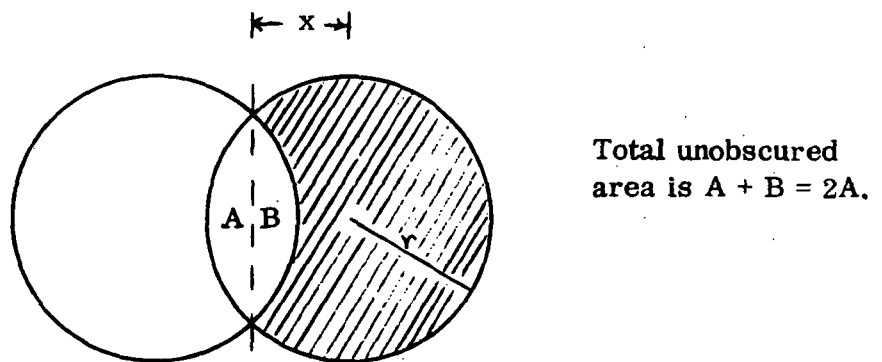
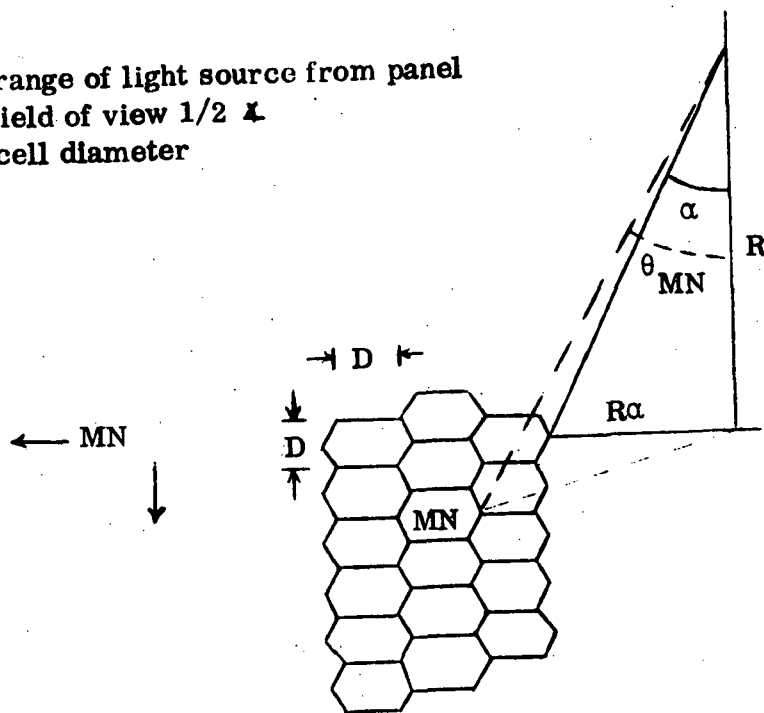


Figure 2. Geometrical Approximation of Unobscured Area.

$R \equiv$  range of light source from panel  
 $\alpha =$  field of view  $1/2 \angle$   
 $D \sim$  cell diameter



$$\theta_{MN} \sim \tan^{-1} \left( \frac{\sqrt{(R\alpha + MD)^2 + (ND)^2}}{R} \right) \quad (4)$$

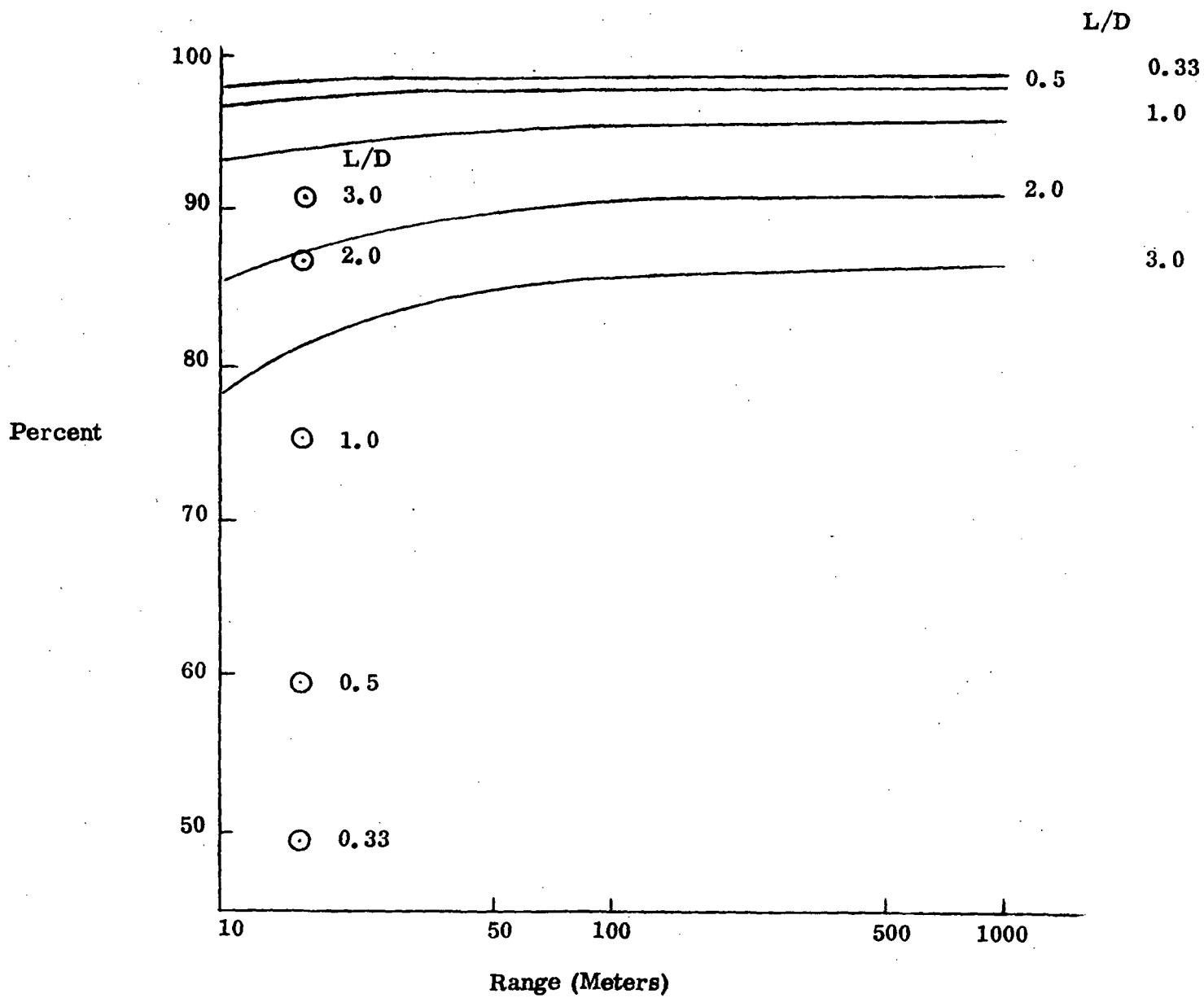
Figure 3. Method of Determining Angle of Incidence.

PROGRAM TO CALCULATE TRANSMISSION THROUGH HONEYCOMB PANEL

```

00010 REAL L,Z
00020 PRINT:"INPUT=CELL LENGTH&DIA,MIRROR DIA,RANGE,ALPHA,DELTA"
00030 PRINT 100
00040 1 READ: D1, L, D2, R, ALPHA, DELTA
00050 PRINT: "CELL DIAMETER=",D1," METERS"
00060 PRINT: "CELL LENGTH=",L," METERS"
00070 PRINT: "MIRROR DIAMETER=",D2," METERS"
00080 PRINT: "RANGE=",R," METERS"
00090 PRINT: "FIELD OF VIEW=",ALPHA," DEGREES"
00100 ALPHA=3.1416/180.*ALPHA
00110 R2=D2/2.
00120 I=D2/D1
00130 * CALCULATE NUMBER OF ROWS IN FIRST COLUMN
00140 J=R2/(2.*D1)
00150 * CALCULATE NUMBER OF COLUMNS IN ARRAY
00160 K=D2/D1
00170 ATOT=0.0
00180 Z=0
00190 J1=J
00200 DO 10 M=1,K
00210 * CALCULATE NUMBER OF ROWS IN COLUMN M
00220 IF(M.LE.K/2+1) J=J+1
00230 IF(M.GT.K/2+1) J=J-1
00240 DO 10 N=1,J
00250 AK=R*ALPHA
00260 IF(J.LT.J1) GO TO 50
00270 * CALCULATE ANGLE OF INCIDENCE
00280 40 THETA=ATAN((SQRT((AK+M*D1)**2+(N*D1)**2))/R)
00290 X=L/2.*TAN(THETA)
00300 * CALCULATE UNOBSERVED AREA OF CELL MN
00310 AMN=2.*(3.141*D1**2/8.-(X*SQRT(D1**2/4.-X**2)
00320 +D1**2/4.*ARCSIN(2.*X/D1)))
00330 * CALCULATE NORMAL CELL AREA
00340 A1=3.141*D1**2/4.
00350 PCMN=AMN/A1
00360 * CALCULATE TOTAL UNOBSERVED AREA
00370 ATOT=ATOT+AMN
00380 Z=Z+1
00390 10 CONTINUE
00400 * NORMALIZE TO OBTAIN PERCENT TRANSMISSION
00410 50 PCTOT=(ATOT/(Z*A1))*100.
00420 PRINT: "NO. OF CELLS=",Z
00430 PRINT: "PERCENT OPTICAL TRANSMISSION=",PCTOT
00440 * CALCULATE PERCENTAGE OF IMPACTS
00450 R=0.0
00460 THETA=0.0
00470 TOTA=0.0
00480 DO 60 I=1,1000
00490 X=L/2.*TAN(THETA)
00500 IF(TAN(THETA).GT.D1/L) GO TO 5
00510 * CALCULATE UNOBSERVED AREA
00520 A=2.*(3.141*D1**2/8.-(X*SQRT(D1**2/4.-X**2)
00530 +D1**2/4.*ARCSIN(2.*X/D1)))
00540 5 IF(TAN(THETA).GT.D1/L) A=0.0
00550 TOTA=TOTA+A
00560 THETA=THETA+DELTA
00570 R=R+1.0
00580 60 IF(THETA.GT.3.141/2.) GO TO 70
00590 * NORMALIZE TO OBTAIN PERCENTAGE OF IMPACTS
00600 70 PCIMP=(1.0-TOTA/(R*A1))*100.
00610 PRINT: "PERCENT PARTICLE IMPACTS=",PCIMP
00620 PRINT 100
00630 100 FORMAT(///)
00640 GO TO 1
00650 END

```



Optical Transmission

○ Particle Impacts

## APPENDIX C



ELEMENT IDENTIFICATION DATA FROM THE  
COMBINED ZODIACAL OPGT EXPERIMENT

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TRW Systems Group  
Redondo Beach, California

January 24, 1972

1. INTRODUCTION

In an attempt to examine the impact on the data one might reasonably expect to obtain from a "Cosmic Dust Analyzer" by integrating it into a combined instrument, a study was conducted at TRW during November and December. A baseline configuration was chosen for the combined instrument and an electronics package capable of retrieving the information from it was designed. Similarly a baseline configuration for an independent CDA was developed. The effect of combining the CDA with an optical detection system and the attendant trade-offs can be determined by comparing hypothetical output data from the two systems.

The instrument under discussion is an impact ionization mass spectrometer. It should be apparent that this description admits the possibility of a number of configurations and philosophies of approach. This is borne out by the fact that groups at the Max-Planck Institute and TRW have independently developed instruments that bear little physical resemblance. The discussion that follows is most likely flavored by our bias in favor of the instrument configuration that we are most familiar with, in spite of our efforts to be objective.

2. EXPERIMENT OBJECTIVES

In principle, it should be possible to obtain the relative atomic abundance of elements contained in cosmic dust particles by a sophisticated version of cosmic dust analyzer. However, this objective doesn't appear to be realizable within the reliability, weight, power, and configuration constraints imposed by the OPGT space craft. In discussion with other members of the Meteoroid Science Mission Definition Team, more realistic

objectives are the following:

- (1) Principle Objective: Determination of the relative magnitudes of the ion signals corresponding to the major constituents of micrometeoroids. This amounts primarily to element identification, but educated guesses can be made about relative abundances of some of the elements.
- (2) Secondary Objective: Determination of the impact rate of cosmic dust particles that produce charge signals above a given detection threshold.
- (3) Secondary Objective: In the combined configuration, simultaneous measurements of impact ionization, impact light flash, and/or impact momentum may permit the determination of micrometeoroid mass and velocity.

The discussion that follows is concerned only with the CDA as it relates to the primary objective of compositional analysis.

### 3. EXPERIMENTAL CONSIDERATIONS

As noted earlier two baseline configurations were used in our study. The first is the combined zodiacal experiment while the other is a cosmic dust analyzer (CDA) only. The CDA we considered is essentially the TRW version. We did not attempt to examine the Max-Planck Institute version of the CDA.

For the combined instrument, the meteoroids impact on electrically biased honeycomb structure located near the outboard end of the optical detector telescope. The accelerated ions drift to the ion collector located near the mirror end of the telescope. For the present study the exact form of the ion collector need not be specified. Conceptually it can be viewed as a metallic disc that is substantially smaller in diameter than the telescope aperture. The distance over which the ion acceleration takes place (i.e., honeycomb to ground grid spacing) is assumed to be small compared to the ion drift distance (i.e., honeycomb to ion collector separation).

In the CDA only configuration, the impact plate is a dish-shaped metallic surface at or near the plane of the spacecraft wall. A conformal grid

is located in close proximity to the target dish. The impact plate is electrically biased with respect to space craft ground. The disc-shaped ion collector is tripod mounted at the center of curvature of the spherical dish.

In either configuration the time-of-flight (TOF) measurement is initiated by sensing the negative pulse at the target. The ions arrive at the collector in groups according to their charge to mass ratio. The data required from a given event are the transit times of the several ion groups and the magnitude of the charge contained in each group. Given the accelerating voltage and the ion flight path length, the ion transit time specifies the charge to mass ratio of the ion. Assuming singly ionized ions (which is most likely as determined by impact tests) specification of the ion charge to mass identifies the element. The magnitude of the charge associated with each ion group yields the number of singly ionized atoms contained in the group.

Although other approaches are possible, we have chosen to integrate the ion current on a capacitor attached to the ion collector. The signal waveform at the collector is stair-step like in appearance. The time at which a given step appears (referenced from the time the particle strikes the target plate) specifies the transit time of that particular ion group. The amplitude of a particular step is proportional to the number of ions of a given charge to mass.

For meteoroids of given composition, the magnitude of the total charge produced varies widely because of differences in impact velocity and mass. We have arbitrarily chosen a dynamic range of  $10^5$  as a design objective. To obtain this dynamic range requirement, the signal at the impact plate is pulse height analyzed and the PHA information is used to select the gain of charge sensitive amplifiers at the collector such that the integrated signal amplitude from the collector lies within the desired range. This approach tacitly assumes that the total integrated charge collected at the ion collector is proportional to the charge leaving the impact plate. It should be noted that this situation is more nearly realizable in the CDA only configuration

than in the combined instrument. This is so because the target is configured such that the electric field vector at any point on the target dish is directed at the center of the ion collector. Except for divergence, all of the emitted ions reach the collector. The ratio of collected to emitted charge in the combined instrument is, however, variable because the ion trajectories are, to first order at least, parallel to the axis of the telescope. Thus, the collection efficiency is larger for ions produced near the center line of the detector than near the periphery. This has the effect that the charge measurement of individual ion groups is less accurate on the average for the combined experiment than for the CDA only configuration.

The inherent resolution of a CDA is determined by the relative magnitudes of directed and random velocities. By this we mean the ratio of the electrically imparted velocity to the thermal velocity. It appears that accelerating voltages in excess of a few hundred volts are large enough to minimize thermal effects.

In a given sampling time interval of the ion collector waveform, the available resolution is determined by the ion transit time. This implies either small accelerating voltage or a long ion flight path. The upper limit to ion flight path length is probably about one meter. The requirement for small accelerating voltage here is in apposition to the requirement for a large directed velocity to thermal velocity ratio. There is still another consideration affecting the choice of accelerating voltage. It has been empirically observed that high voltages (or fields ?) are required to extract hydrogen ions from the impact plasma. Unless future experiments prove otherwise, we will assume that a minimum accelerating potential of 1000 volts and a corresponding electric field of about 1000 volts/cm are required to extract  $H^+$  from the plasma.

---

The sampling rate of the ion collector signal (i.e., the frequency at which the amplitude of the signal is measured) is also determined by practical considerations. There is no point to sampling the waveform at time intervals shorter than the inherent resolution of the instrument. Likewise

if too slow a rate is used, available information is lost. A 2-mega Hertz rate seems amply fast and, since a 2-mega Hertz clock is available from the space craft, we have chosen this rate for baseline purposes. To go beyond this rate would cause an increase in weight, power, and complexity that doesn't seem justified on the basis of the other factors mentioned above. In fact, it might be possible to get by with a 1-mega Hertz rate for the CDA only configuration.

#### 4. TIME-OF-FLIGHT ELECTRONICS SYSTEM

The general principles embodied in the electronic system described below are applicable to either configuration. Depending upon the particular configuration chosen, however, the data acquisition subsystem can be optimized in terms of reliability, redundancy, and power and weight minimumization. For example, 1  $\mu$ sec sampling intervals might well be fast enough for a one meter long system. However, the toggling between two sample and hold systems could be retained for purposes of redundancy.

The system described below represents a significant improvement over the system previously developed at TRW. The improvement was made possible by the availability of fast (0.8  $\mu$ s) analog to digital converters. Our previous design required a sample and hold circuit for each channel. The fast A-D converter allows the use of only one, or at most two, sample and hold circuits. The A-D converter takes a large amount of power and, hence, power gating has been incorporated into the system where possible.

##### 4.1 General Description

The TOF electronics is divided roughly into three major subsystems as follows:

1. Target Electronics and Level Set,
2. Collector Electronics and Gain Change and
3. Data Acquisition and Control.

The Target Electronics analyzes the charge produced by the impact of a cosmic dust particle and produces a 3-bit code to set the gain of the collector electronics before the charge arrives at the collector. It also produces a target pulse which turns on the high speed electronics in the Data Acquisition and Control.

The collector electronics produces an output signal proportional to the collected charge and is adjusted by the gain change code. The collector signal is integrated by a sample and hold circuit. The charge attributable to each charge/mass ratio takes a certain time to arrive at the collector depending on the drift tube geometry and potentials. The time of arrival for each mass number (assuming singly charged ions) can be predicted with reasonable accuracy. The total drift time is divided into 32 segments of either 0.5  $\mu$  sec or 1.0  $\mu$  sec, depending on the length of the ion flight path.

The Data Acquisition and Control digitizer samples at 0.5 or 1.0  $\mu$  sec intervals and stores the resulting binary numbers in a 32-word by 8-bit bipolar random access memory. When this is completed, the data is transferred to the telemetry in 8-bit words at the telemetry readout rate.

#### Collector Electronics

The collector electronics is discussed first because its characteristics define some of the requirements of the Target Electronics and Level Set subsystem.

It is required that five orders of magnitude in charge be covered, full scales of  $5 \times 10^{-13}$  coulombs through  $5 \times 10^{-9}$  coulombs. This broad range of gains is achieved by charge division between two charge sensitive amplifiers and selection of other amplifiers. The two positions of highest gain,  $5 \times 10^{-13}$  coulombs full scale and  $5 \times 10^{-12}$  coulombs full scale are achieved when using the upper charge sensitive amplifier, CSA4 and the remainder of the ranges use CSA3. To achieve the full five decodes, the following table is effective.

Range	Coulombs Full Scale	Preamp Gain V/Coulomb	Post Amp Gain	Amp In	CSA Bit	2	1
1	$5 \times 10^{-13}$	$2 \times 10^{11}$	10	A4,A5	0	0	1
2	$5 \times 10^{-12}$	$2 \times 10^{11}$	1		0	1	0
3	$5 \times 10^{-11}$	$2 \times 10^8$	100	A3,A4,A5	1	0	0
4	$5 \times 10^{-10}$	$2 \times 10^8$	10		1	0	1
5	$5 \times 10^{-9}$	$2 \times 10^8$	1		1	1	1

It should be noted that the 3-bit code does not correspond to the binary equivalent of the range number. Binary 000 and 011 are excluded. This is necessary because the first two ranges are the only ones using the  $2 \times 10^{11}$  volt/coulomb preamp. The output signal from the preamp selected by  $S_3$  is amplified by a combination of amplifiers depending on the code of the gain set lines. If both  $S_1$  and  $S_2$  are in the normal position (not energized), the output gain is 100. If  $S_1$  alone is energized, the gain is 10 and if  $S_2$  alone is energized, the gain is 1.0. Amplifier A5 is a follower which lowers the output impedance. In the arrangement of the codes, code 000 is excluded but until the gain setting operation is completed, the amplifiers are in this state. This selects the  $2 \times 10^{11}$  volt/coulomb CSA plus an additional gain of 100, producing a saturated output. For this reason, the sampling of the output voltage is delayed for 2  $\mu$ s, until the gain switching takes place.

#### Target Electronics and Level Set

When a dust particle impacts the target, the charge in the target pulse is divided between the two charge sensitive amplifiers, CSA1 and CSA2. CSA2 receives 100 times as much charge as CSA1. The output of CSA2 rises first after a particle impact and after it is amplified by amplifiers A6 and A7 is the first output to be evidenced. This is called the target pulse. The target pulse sets FF-1 and turns on the data acquisition and control system's high speed electronics. As the target pulse rises, its amplitude

will be sensed first by comparator C1, then C2 and so on until it rises to its maximum. A signal which causes comparator C5 to change state will also cause all others with lower numbers to change state.

The logic changes these inclusive outputs into discrete lines by using an inverter output from the next highest level as an input to each decoder gate; thus, if comparators C1 through C4 are triggered, inverters  $I_1$ ,  $I_2$  and  $I_3$  cause a logic zero to appear at the input of gates  $G_1$ ,  $G_2$  and  $G_3$ . This ensures that only one output logic line is true at any one time.

The five discrete lines representing the five decades of input range are in inverted logic where zero is true.

Since the logic is inverted at this point, NAND gates can be used as NOR gates to encode the data into 3 lines. The three latches composed of  $G_5$  through  $G_{11}$  form the encoder. The latches are held in the reset state for 300 ns when the "clear" pulse arrives. This allows time for the target pulse to rise to its maximum. An additional 100 ns one-shot triggers when the 300 ns one-shot falls. This gates data through  $G_1$  through  $G_5$  and assures that no other data comes through until the system is reset. The latches hold the level until the next meteoroid impact.

#### Data Acquisition and Control

In the sequence of events, the first occurrence is that the target pulse sets flip flop FF1. With FF1 set, several things begin to happen. All of the high speed, high power electronics in the Data Acquisition and Control is power gated. This includes the A-D converter, the random access memory and all of the ancillary logic and control. The power turns on when FF1 is set. A one-shot labeled "clear" produces a 50 ns pulse which clears all logic and the sample and hold circuits.

---

~~Since it takes some time to measure the target charge and set the gain,~~  
all data-taking functions are delayed 2  $\mu$ s by a one-shot. Any charge reaching the collector within 2  $\mu$ s is due to hydrogen and is stored on the collector anyway, so delaying the data taking is not a disadvantage. During



the  $2 \mu s$  period, all sample and hold circuits are being cleared. When the  $2 \mu s$  period ends, the main sample and hold is placed in the "sample" state and the clock signal is gated on.

In the  $0.5 \mu s$  clock interval system, the clock signal toggles FF4 and the outputs control A-D converters #1 and #2 alternately. While A-D converter #1 is operating, auxiliary sample and hold #2 is accepting a sample and vice versa.

The A-D conversion takes  $0.8 \mu sec$ . When this is completed, one-shot 1 produces a  $100 ns$  pulse loading the contents of the converted word from the A-D converter into the first word of the random access memory (RAM) through the multiplexer. One-shot 2 produces a pulse which goes through  $G_{12}$  and  $G_{17}$  to advance the address counter 1 bit. The second input of  $G_{13}$  is a "1" because FF2 and FF3 are both in the zero state. The next clock pulse repeats the operation and loads the other A-D output into word 2 of the RAM and so on.

It is in order at this point to explain the signal process in the sample and hold circuits. Two  $\mu s$  after a target pulse occurs, the main sample and hold starts to integrate all signals and does so throughout the period during which data is being acquired. The auxiliary sample and hold rises to match the contents of the main sample and hold during the  $100 ns$  clock pulse. It stays at this level until the next clock pulse and then again rises to match the contents of the main sample and hold. The result is that at the end of the data acquire period, the last auxiliary sample and hold to be used will contain the same level as the main sample and hold, i.e., the total integrated collector charge.

The system records 32 samples as described above. The next clock pulse sets FF2 and closes gate  $G_{13}$  as FF2 produces a true output on "Q". Gate  $G_{14}$  is enabled allowing access from the 3-bit word counter. It is now setting at 0, 0, 0. Gate  $G_{15}$  is enabled by FF2 being true, FF3 being false, the 3-bit counter at 000 and the word gate from the spacecraft telemetry rising. It can thus be seen that nothing will happen until the word gate rises.

When this occurs, one-shot 3 produces a pulse which loads the first RAM word into an 8-bit register. After 8 shift pulses, the 3-bit counter is again at 000 and the second word is loaded. When the main register is loaded, the 3-bit gain set register is also loaded. The 3 gain set bits remain in the same state throughout any one data readout period so the fact that loading is repeated 32 times does not affect the correct operation of the system. The 3 bits will be read out only once per data acquire cycle. When all 32 words are shifted out, FF3 changes state. This sends a clear signal to FF1 turning off the major components of the Data Acquisition and Control and enabling the target electronics in readiness for another event.

## 5. CONCLUSIONS AND SUMMARY

It appears that adequate experimental data can be obtained from a cosmic dust analyzer on the OPGT Missions whether it is used in combination with other sensors or individually. However, better resolution and accuracy can be obtained with the CDA only. This is because the flight path length can be made longer and the ion extraction geometry can be optimized. Both of these factors affect the resolution. As noted earlier, the amplitude of the collector charge steps can be measured with better accuracy with the CDA only configuration.

To compare the possible data return from the two configurations, we have assumed an idealized waveform at the collector and show graphically the data that would be returned from the two configurations. For illustrative purposes only we have assumed an atomic abundance as given by Öpik for meteorite falls. We further assume that the ions are in the same ratio as the neutral atom fraction. We then calculate the ion transit time for two sets of conditions:

(1) Accelerating voltage = 1000 volts  
Ion flight path length = 1 meter

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(2) Accelerating voltage = 1000 volts  
Ion flight path length = 30 cm.

The results are tabulated in Table I. We have normalized the hypothetical number of ions of each species to oxygen which is assumed to be unity.

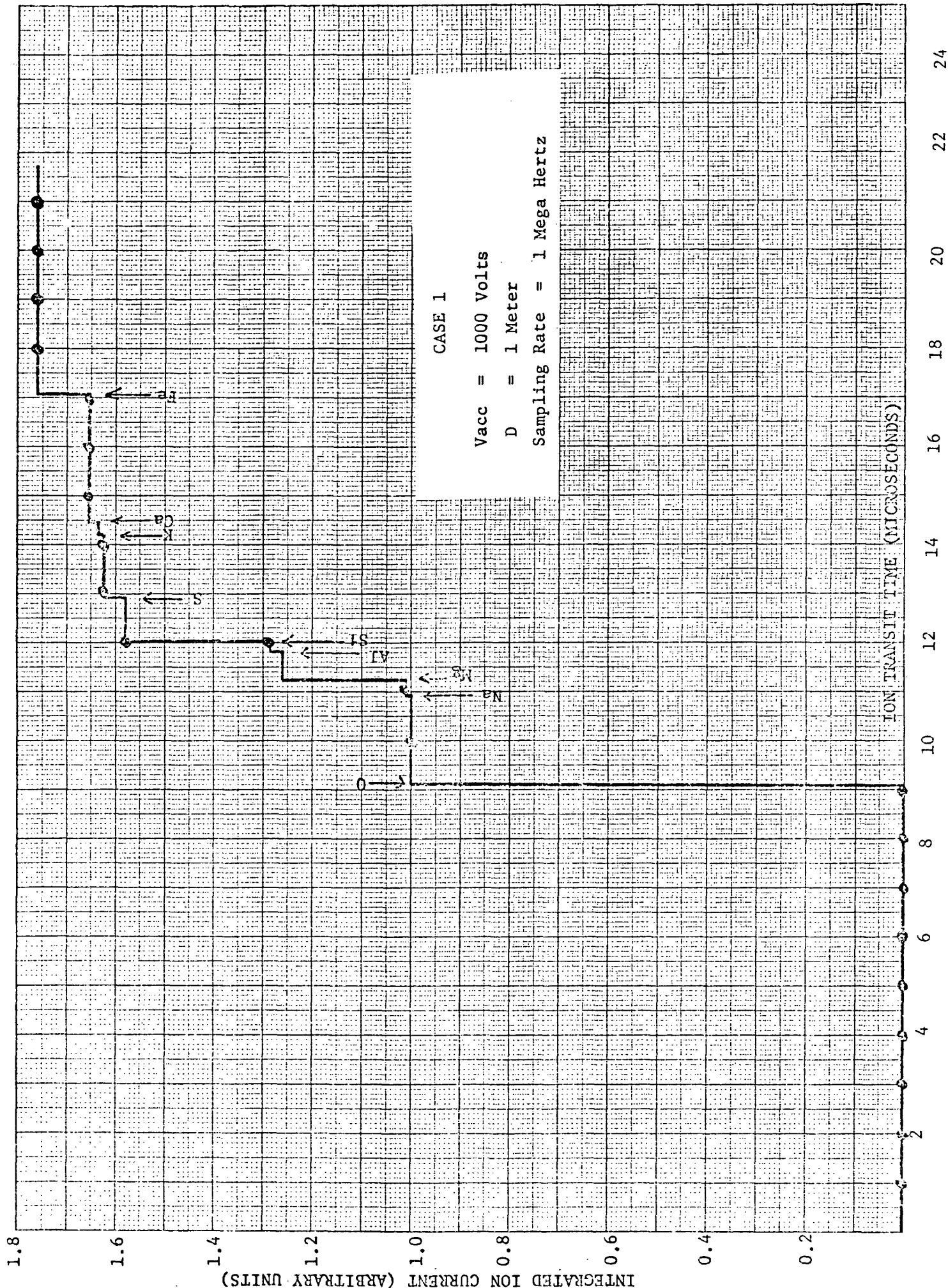
TABLE I

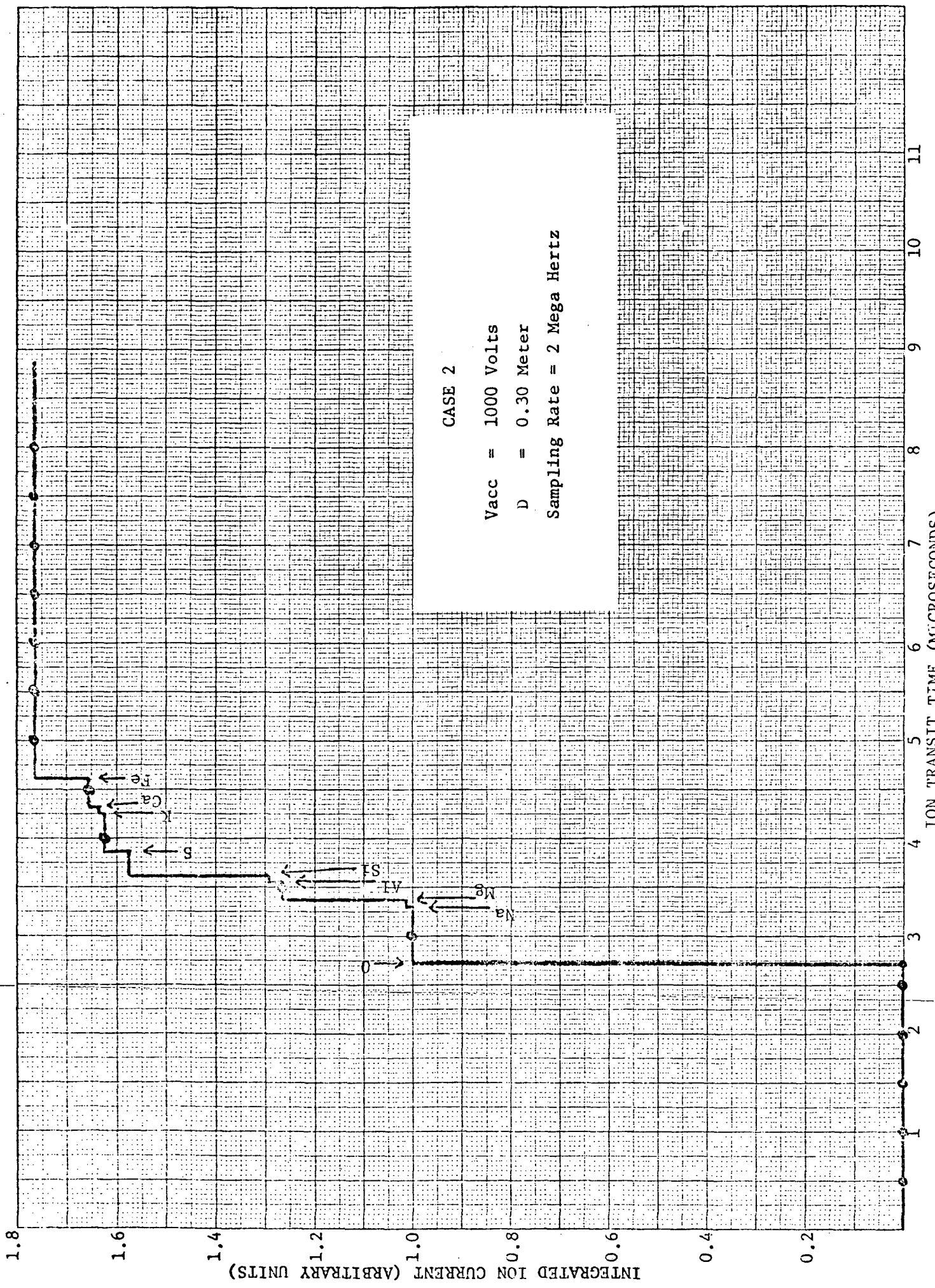
<u>ELEMENT</u>	<u>ATOMIC WEIGHT</u>	<u>ABUNDANCE (0 <math>\equiv</math> 1)</u>	<u>ION TRANSIT CASE 1</u>	<u>TIME (<math>\mu</math> sec) CASE 2</u>
OXYGEN (O)	16	1.00	9.1	2.73
SODIUM (Na)	23	.012	10.9	3.27
MAGNESIUM (Mg)	24	.252	11.2	3.36
ALUMINUM (Al)	27	.023	11.8	3.54
SILICON (Si)	28	.291	12.0	3.60
SULPHUR (S)	32	.048	12.9	3.87
POTASSIUM (K)	39	.009	14.2	4.25
CALCIUM (Ca)	40	.018	14.4	4.32
IRON (Fe)	56	.111	17.0	5.10

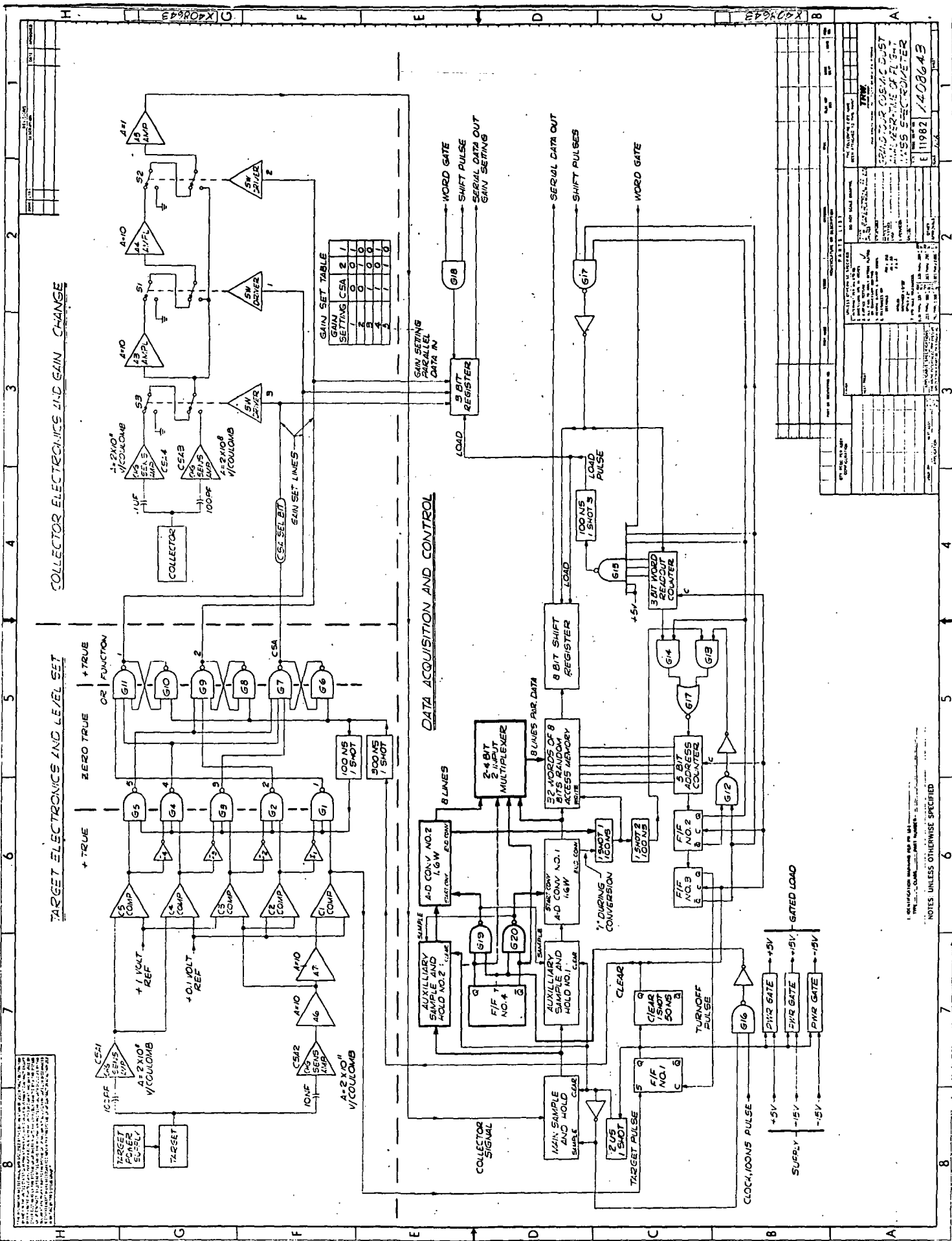
Idealized ion collector waveforms for the two cases are shown in the figures. The heavy dots represent the points at which the waveform is sampled. Here we have assumed 0.5  $\mu$ sec sampling intervals for Case 2 and 1  $\mu$ sec intervals for Case 1. In both cases, the waveforms are sampled with sufficient frequency to separate the major steps into different intervals.

In practice the results are not likely to be as good as for these idealized cases due to finite rise time, inaccuracies in the amplitude measurement, and other factors. However, the purpose of this exercise was to evaluate the consequences of combining the CDA with other types of detector. The conclusion is that, although there may be some loss in data obtained and a somewhat more complex system is required, the CDA can deliver useful data within the constraints imposed by the combined zodiacal experiment.

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## APPENDIX D



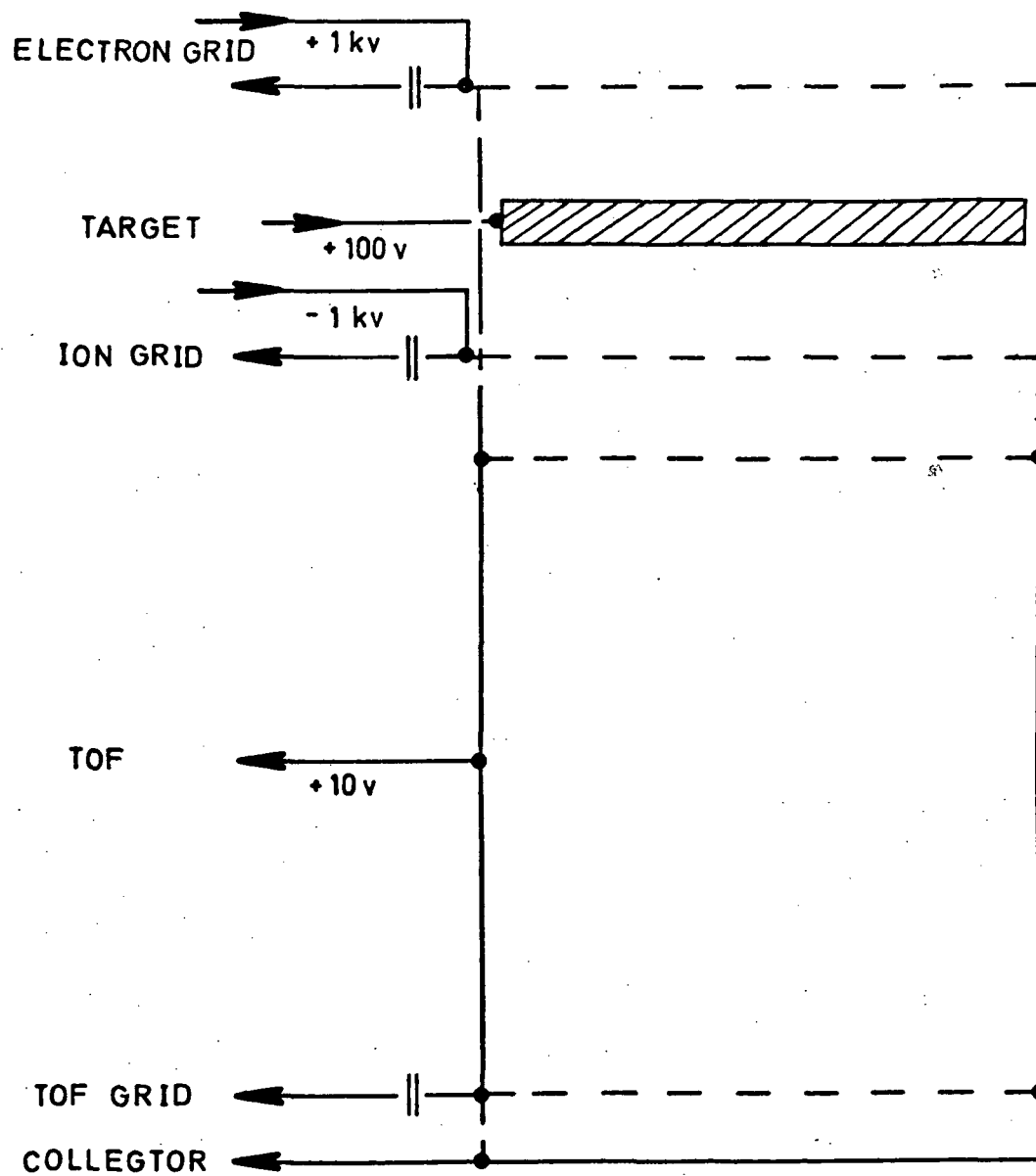
DESCRIPTION  
OF A  
COMBINED COSMIC DUST ANALYZER  
FOR  
THE GRAND TOUR MISSIONS TO  
THE OUTER PLANETS

prepared by the

Max Planck Institut für Kernphysik  
Heidelberg, Germany

## Contents

1. Description of Electronics Requirements
  - 1.1 Configuration of Sensors
  - 1.2 Interfaces
  - 1.3 Requirements
2. External Interfaces
  - 2.1 S/C Interfaces
  - 2.2 Interfaces to Combined Cosmic Dust Analyser
3. Electronic System Description
  - 3.1 Signal Conditioning of Electron Pulses
  - 3.2 Signal Conditioning of Ion Pulses
  - 3.3 TOF Grid Pulses
  - 3.4 Signal Conditioning of Collector Spectrum
  - 3.5 Impact Detection
  - 3.6 Start of Signal Conditioning Phase
  - 3.7 Coincidences
  - 3.8 S/C Time
  - 3.9 Data Memory
  - 3.10 Data Frame
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  - 3.12 Programmer, Encoder and Impact Counter
  - 3.13 Filtering of Power Supply and Pulsed Power Supply
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  - 4.1 Power Dissipation
5. Packaging
  - 5.1 Weight



CONFIGURATION OF EXPERIMENT

## 1.3.10

## Data Format

<u>Nr.</u>	<u>Signal Source</u>	<u>Signal</u>	<u>Bits</u>
1	Electron Grid	Electron Amplitude	5
2	Ion Grid	Ion Amplitude	5
3	Time of Flight Tube	TOF Grid Ampl.	4
4	Collector	Spectrum Ampl.	64
5	Collector	Spectrum Masses	96
6	Electron Grid	Rise Time	4
7	Ion Grid	Rise Time	4
8	TOF Tube	Rise Time	4
9	Coincidences	Impact Counter	6
10	Ion-Electron-Grid	Ion-Electron-Coin.(long)	1
11	Ion-Electron-Grid	Ion-Electron-Coin.(short)	1
12	Ground Command	Test Flag 1	1
13	Ground Command	Test Flag 2	1
14	S/C	Time	12
15	Digital Housekeeping	Spare	32
Sum			<hr/> 240 Bits

### 1.3.11 Test Pulses

For in-Flight-calibration two several testpulses of below defined charges have to be generated. Into the corresponding format a flag has to be set.

Testpulse data in the memory have preference to impact data.

#### 1.3.11.1 Test Pulse 1

<u>Channel</u>	<u>Amplitude</u>	<u>Rise Time</u>
Ions	+ $10^{-13}$ Cb	1 us
Electrons	- $10^{-13}$ Cb	1 us
TOF	- $10^{-13}$ Cb	1 us

#### 1.3.11.2 Test Pulse 2

<u>Channel</u>	<u>Amplitude</u>	<u>Rise Time</u>
Ions	+ $10^{-11}$ Cb	4 us
Electrons	- $10^{-11}$ Cb	4 us
TOF	- $10^{-11}$ Cb	4 us

### 2.1.2 Low Voltage Power Supply

It is assumed to get all voltages from S/C. For values see power chapter. The ripple is assumed with  $20 \text{ mV}_{\text{pp}}$  at 100 kHz.

To minimize the power dissipation the digital circuitry is supplied during signal conditioning phase only excepting the data memory which has to be supplied until the data are read into the main memory of the CCL. During this time the signal conditioning system cannot be initiated by an impact.

## 2.2 Interfaces to Combined Cosmic Dust Analyser

### 2.2.1 Clock.

It is assumed to get a 2 mHz clock signal. All of the needed pulses within the electronics will be derived from this clock.

### 2.2.2 Data Output

Because two redundant output memories are used, two data lines come out of the experiment. The final lay-out of data read depends on the lay-out of the CCL.

A ready signal will be given at the end of data write-in to the 240 bit memory. After read-out a flag will be needed to be ready for another impact.

Bit shift pulse will be needed from S/C too.

### 2.2.3 High Voltage

It is assumed to get the high voltages of + 1 kV and - 1 kV from the CCL. The ripple should not be greater than  $10 \text{ mV}_{pp}$  at 100kHz.



### 3. General System Description.

The following gives some description of the functioning of the system:

When an impact is detected by the signal conditioning of the electron or ion grid (the electron grid detection can be switched off) all digital subsystems will be switched on during the time less than 1  $\mu$ s. With a short delay the digital circuitry will be cleared. The peak time of the ion pulse is used as reference signal to start the collector signal conditioning subsystem. 2,2  $\mu$ s later the mass selection counter starts. It is possible to get a time resolution of 0,25  $\mu$ s.

The digital peak time detector controls the 240 bit memory which reads the outputs of the logarithmic ADC and the mass selection counter with four and six bits respectively. This way it is possible to storage mass and amplitude information of 16 masses out of a range of 64 steps corresponding to the masses from 1 to 60.

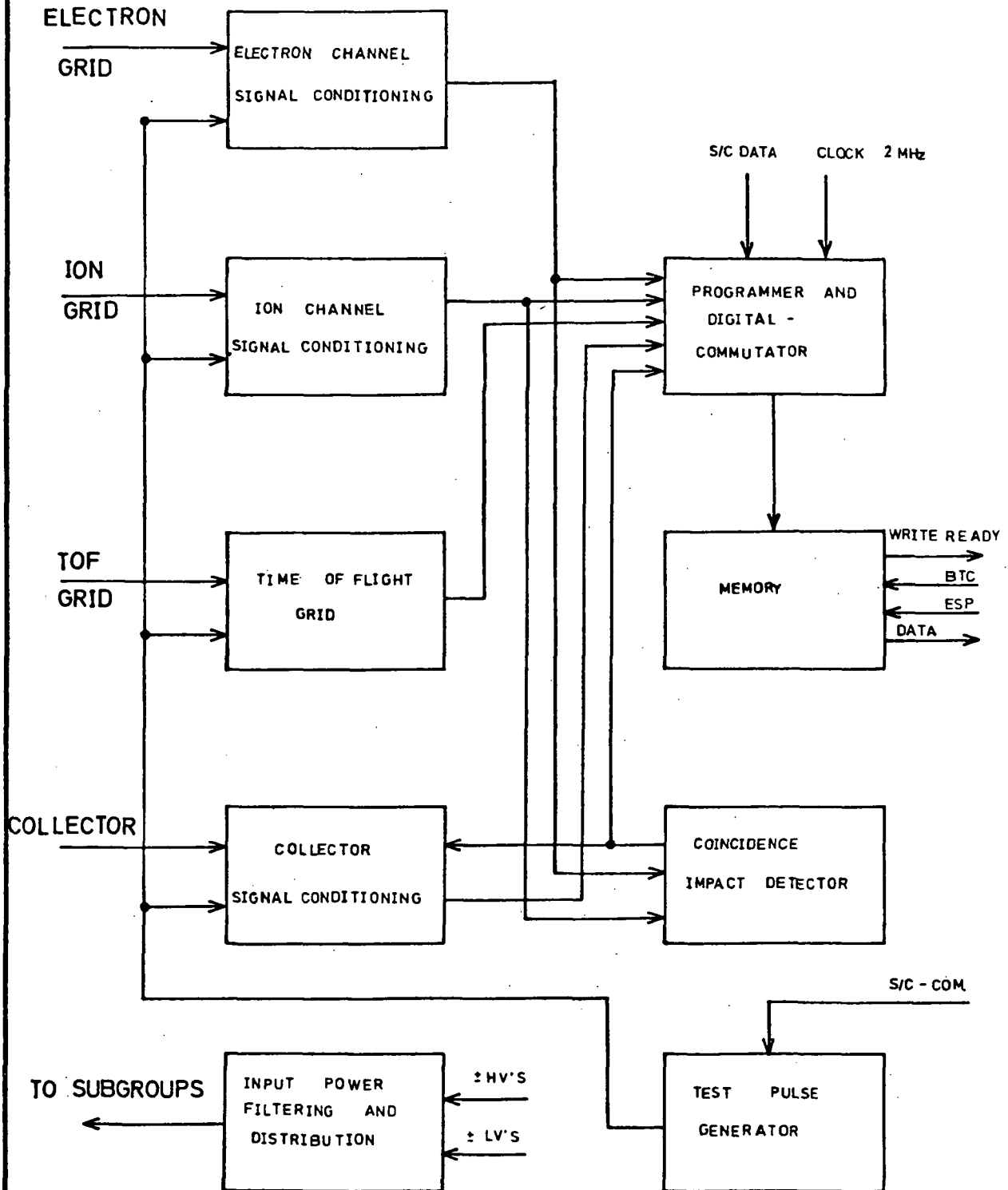
While the collector signal conditioning subsystem analyses the spectrum, the grid signal conditioning subsystems convert the amplitudes and rise times into digital forms. This information is stored in the ADC counters which are used as buffer memories. Encoding and buffering of this information into the the 240 bit memory takes place after the spectrum data. After writing in the coincidences and other information the memory gives a ready signal to the Combined Cosmic Dust Analyser memory or to the CLL-Unit. At the same time ~~the digital circuitry is switched off.~~

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After read-out of the 240 bit memory, this memory can be switched off too.

Because of reliability reasons the test pulses can be generated by ground commands only.

# BLOCK DIAGRAM



To get a very high reliability the use of two identical subsystems is proposed. One of the two subsystems is switched on by switching on the power supply. To switch on the redundant subsystem a ground command has to be sent. At the same time the subsystem which has been giving incorrect data is switched off.

Some circuitry (i.e. ps-filtering) cannot be switched over. This circuitry is designed in "hot redundant" lay-out by quad configuration of components.

### 3. 1/2 Electron and Ion-Grid Signal Conditioning.

The charge pulses from  $5 \cdot 10^{-15}$  to  $5 \cdot 10^{-9}$  Cb are converted into voltages from 0,6 mV to 6 V by charge sensitive amplifiers..

The logarithmic ADC converts these voltages into numbers within the range of 0 to 23. These numbers are stored after analog to digital conversion in the ADC counters ready for writing into the 240 bit memory by the digital commutator.

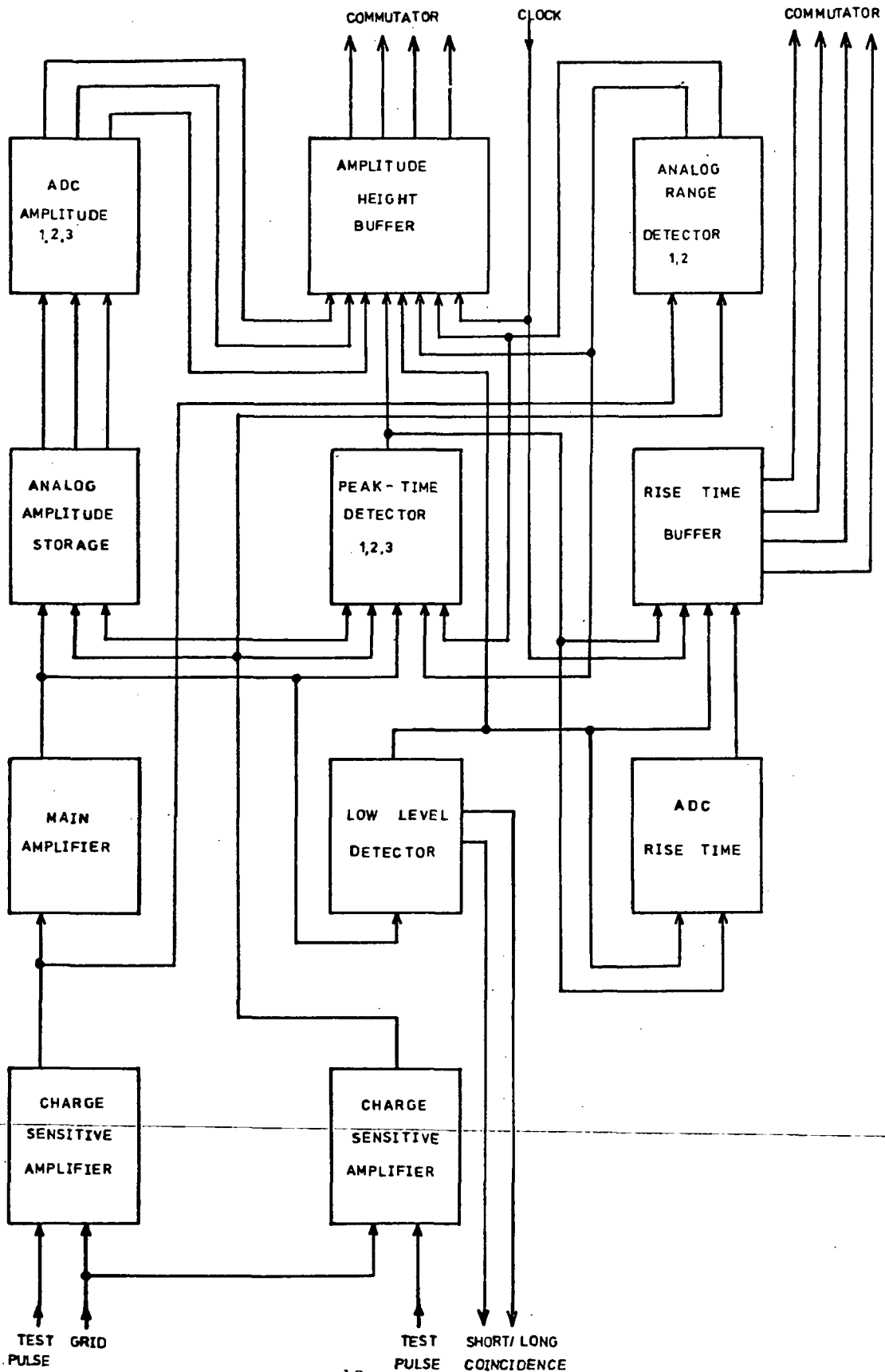
This unusually high voltage of 0,6 mV for the lower limit of the signal range is chosen to decrease long time effect and radiation degradations during the long mission.

The output of the low level detector is used to start the rise time measuring circuit, for resetting and as input to the coincidence circuits.

The rise time ADC functions the same way as amplitude ADC. It converts rise times from 1 to 5 us into numbers from 0 to 15.

The whole conditioning channel can be checked and calibrated if needed by two several test pulses.

### 3.1 SIGNAL CONDITIONING ELECTRON GRID + ION GRID (CIRCUITRY FOR ONE CHANNEL ONLY)



### 3.3 Time of Flight Grid Signal Conditioning

This channel differs from the electron signal conditioning channel by the range only. Therefore it does not need the second charge sensitive amplifier, the third amplitude ADC and the second range detector.

### 3.4 Signal Conditioning Channel of Collector Spectrum

#### 3.4.1 Amplitude

The input range is  $10^{-14}$  Cb to  $10^{-10}$  Cb.

For the voltage range at the outputs of the charge sensitive amplifiers the same values are chosen as for the grid amplifiers.

The logarithmic ADC converts in a free running mode and is also used for detecting the peak time of masses. This signal is used to write the 4 bit amplitude and 6 bit time information gray coded into the 240 bit memory.

#### 3.4.2 Mass Detection

The mass selection counter will be started 2,2 us after the ion peak time was detected. This time corresponds to the mass no. 1. The following time of 16 us can be read out in steps of 0,25 us. This way it is possible to storage any 16 masses within the spectrum from mass no. 1 to mass no. 60 with a time resolution of 0,25 us.

### 3.5 Impact Detection

The start pulse will be derived from the electron or ion low level detector.

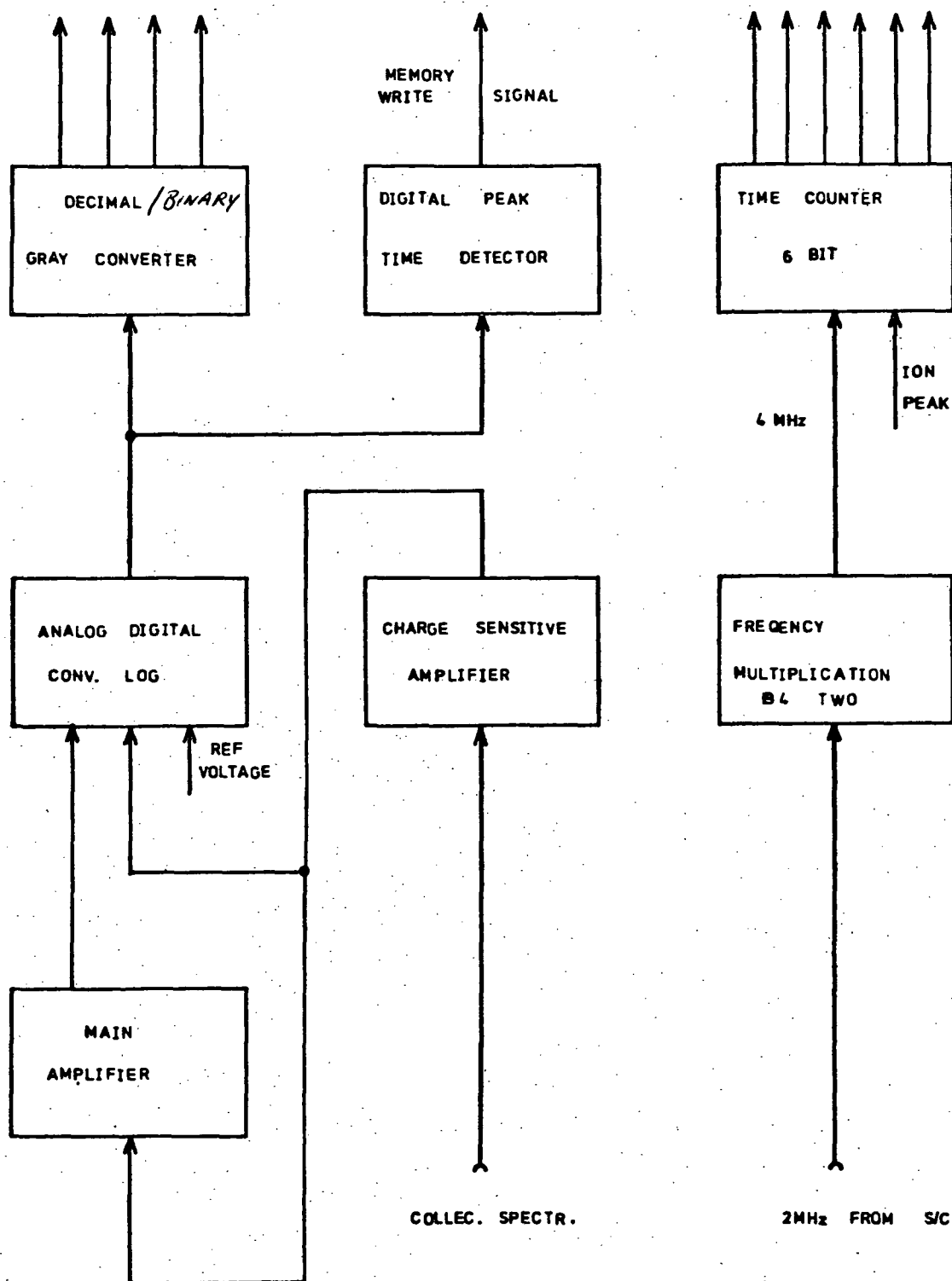
### 3.6 Start of Signal Conditioning

The signal output of the impact detection circuitry is used to start the grid and collector conditioning channels.

### 3.7 Coincidences

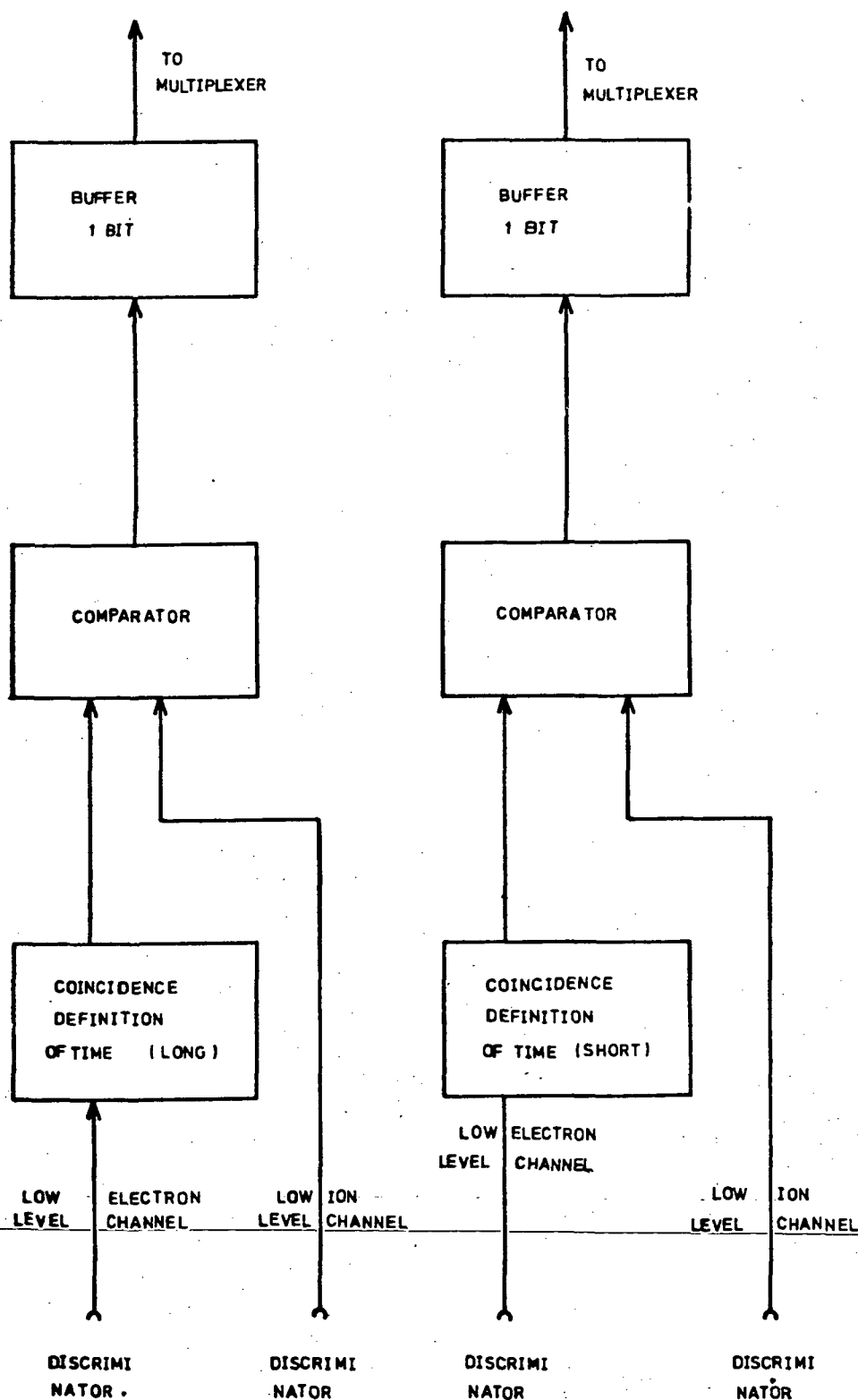
This circuitry is conformed in the usual way of comparing signals where one of it is delayed properly.

# 34 SIGNAL CONDITIONING COLLECTOR DATA MEMORY





### 3.7 COINCIDENCES



### 3.8 Time

It is assumed to write the parallel time information of 12 bits into the 240 bit memory. It is not foreseen to buffer this time information within the experiment. Therefore a write-in pulse will be needed from the S/C. This information will be commutated at each impact time.

### 3.9 Data Memory

This memory will be built with TTL-Shift registers. (SNR-54).

This memory will be switched on by the impact detector. If it is built up with 240 bits a signal will be given to the CCL. After it is read out it will be switched off automatically.

### 3.10 Data Frame

See chapter 1.3.10.

### 3.11 Test Pulses

Different test pulses can be performed (by ground commands) as required. Two certain voltage pulses with defined rise times and amplitudes are fed into two capacitors at the input of the charge sensitive amplifiers.

### 3.12 Programmer, Encoder and Impact Counter

The Programmer controls all the digital functions within the experiment. The start pulse is derived from the the impact detector. This part of the digital circuitry will be switched off after about two ms. After read-out of the 240 bit memory by the CCL this memory will also be switched off.

An impact counter is clocked by each impact detector signal. This way it is also possible to count impacts during the time the 240 bit memory is working in the read-out phase.

### 3.11 Test Pulses

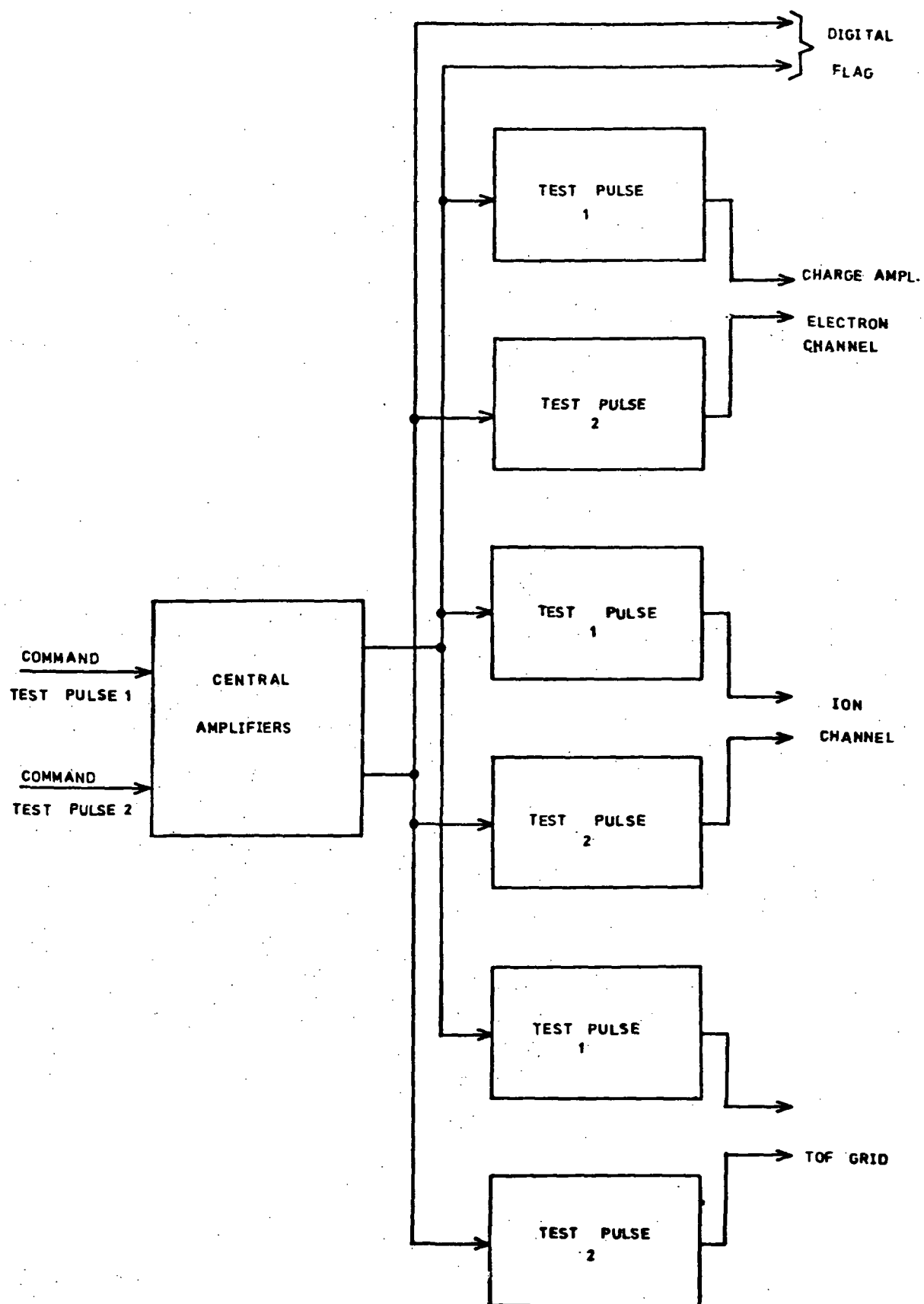
Different test pulses can be performed (by ground commands) as required. Two certain voltage pulses with defined rise times and amplitudes are fed into two capacitors at the input of the charge sensitive amplifiers.

### 3.12 Programmer, Encoder and Impact Counter

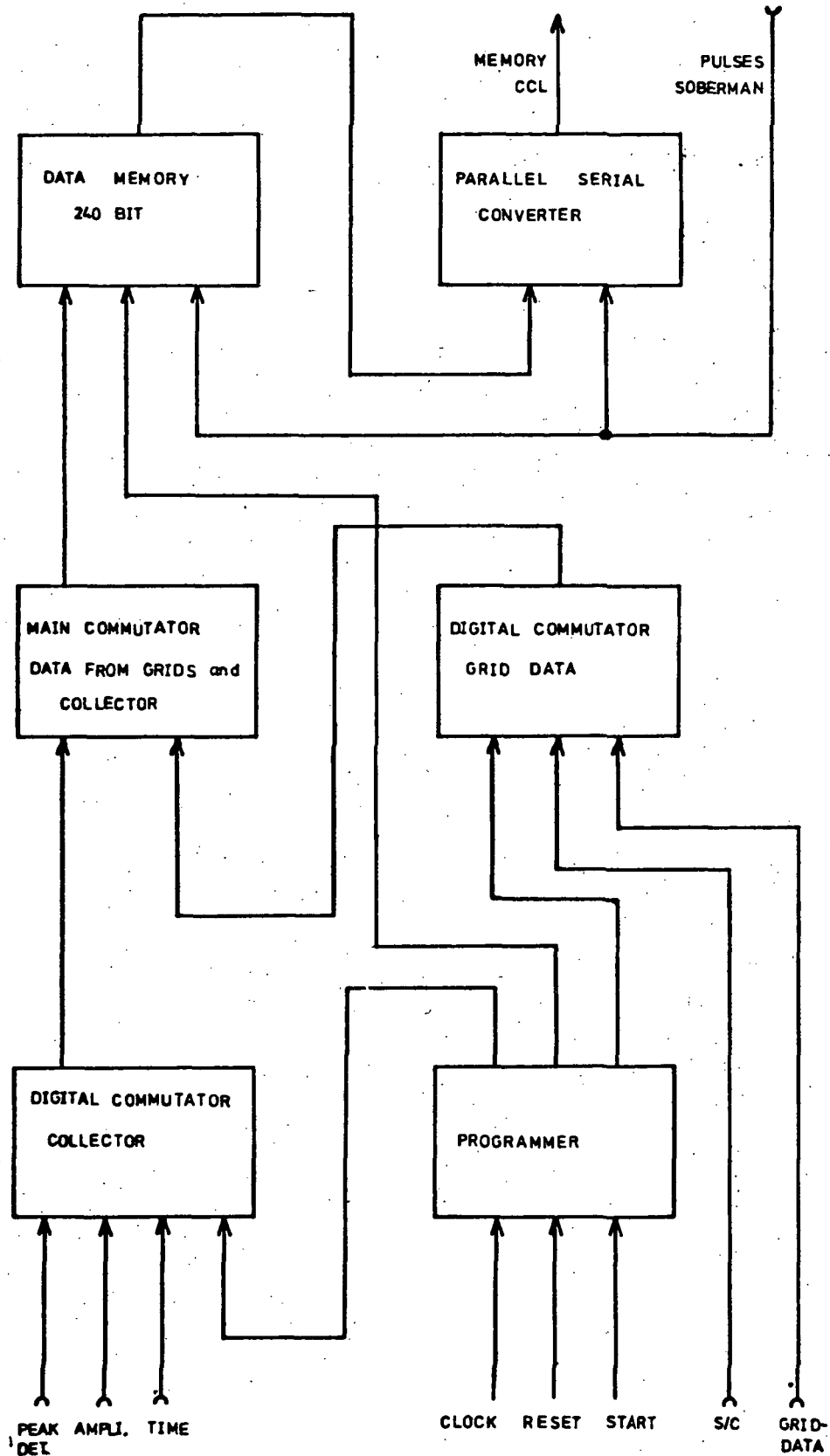
The Programmer controls all the digital functions within the experiment. The start pulse is derived from the impact detector. This part of the digital circuitry will be switched off after about two ms. After read-out of the 240 bit memory by the CCL this memory will also be switched off.

An impact counter is clocked by each impact detector signal. This way it is also possible to count impacts during the time the 240 bit memory is working in the read-out phase.

### 3.11 TESTPULSE GENERATOR



### 3.12 PROGRAMMER and DIGITAL COMMUTATOR



#### 4. Power.

As mentioned in the respective chapters this electronic system consists of three differently supplied groups of subsystems:

Group 1: To be supplied continuously.

Group 2: To be supplied for 2 ms beginning with each detection of an impact.

Group 3: To be supplied for readout time which is defined by the delay between the memory readout ready signal and the beginning of readout by the CCL and the bit shift pulse frequency which must be less than 300 kHz.

#### 4.1 Power Dissipation

##### Group 1:

Nr.	+ 5 V $\pm$ 5%	+ 10 V $\pm$ 2%	- 10 V $\pm$ 2%	+ 6 V $\pm$ 2%	- 6 V $\pm$ 2%
3.1	21	334			150
3.2			240	209	
3.3	21	215		100	
3.4	14		50	75	75
3.7	15				
3.13		10			
	92 mW	559 mW	290 mW	384 mW	225 mW

Sum of continuous power: 1 150 mW  
=====

##### Group 2:

Nr.	+ 10 V (To get + 5 V pulsed voltage)
3.1	35
3.2	35
3.3	35
3.4	28
3.11	5
3.12	190

328 mW pulsed power for 2 ms

With a duty cycle of  $\frac{2\text{ms}}{5\text{s}}$  results an average power consumption of 0,13 mW.

A capacitor of 22 uF and a current limiting resistor of 100 kOhm have to be used. The loading current is less than 50 uA.

##### Group 3:

Nr.	+ 10 V (To get + V pulsed voltage)
3.9	760 mV pulsed power

The minimum switchon time is: Write in phase 2 ms

Read out phase  
at 300 kHz shift  
pulse ca. 1 ms  
ca. 3 ms

A capacitance of 120 uF and a current limiting resistor of 18 kOhm have to be used. The loading current is less than 250 uA.



## 5. Packaging

It is assumed to use baby boards with an area of about 50 cm<sup>2</sup>. Some parts of the electronics have to be put into shielding housings. The weight for these housings is included in the mass breakdown.

It is necessary to locate the analog circuitry (Charge sensitive amplifiers and main amplifiers) of the signal conditioning channels near the sources.

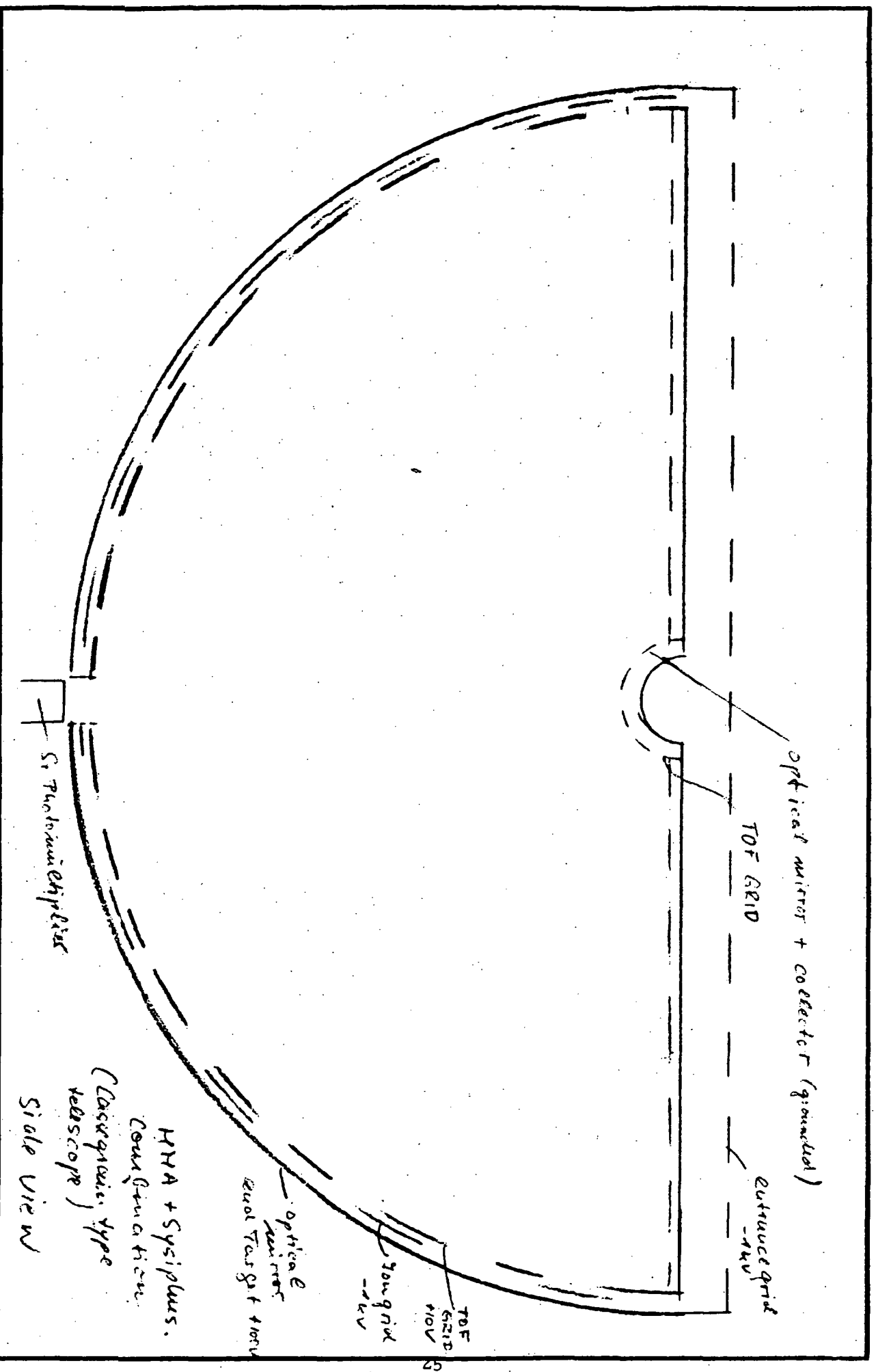
### 5.1 Mass breakdown

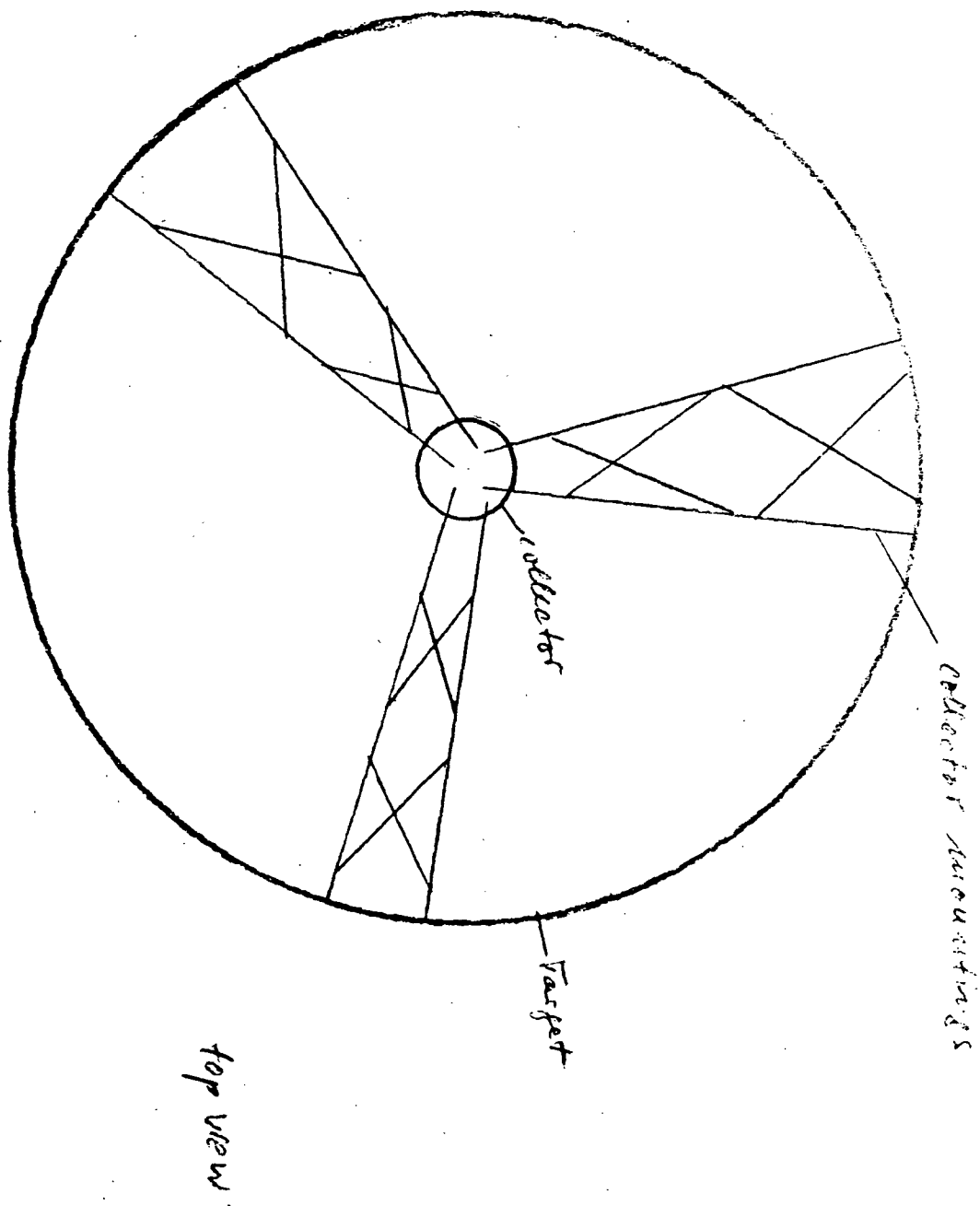
<u>Nr.</u>	<u>Electronics incl. Babyboards (g)</u>	<u>Shielding housings (g)</u>
3.1	173	30
3.2	173	30
3.3	94	15
3.4	140	8
3.5	-	-
3.6	-	-
3.7	20	-
3.8	-	-
3.9	36	-
3.10	-	-
3.11	40	-
3.12	45	-
3.13	120	30
<hr/>		<hr/>
851 g		113 g

Total mass of electronics will be about 964 g.

Total mass of redundant electronics will be about 814 g.

For this calculation it is assumed to use discrete analog electronic components only. The use of analog integrated circuit would reduce the weight.





## APPENDIX E



MISSILE AND SPACE DIVISION  
PHILADELPHIA

# PROGRAM INFORMATION REQUEST / RELEASE

	*CLASS. LTR.	OPERATION	PROGRAM	SEQUENCE NO.	REV. LTR.
PIR NO.	1244	— 1244	— 00	— 103	
*USE "C" FOR CLASSIFIED AND "U" FOR UNCLASSIFIED					

FROM	V. F. Mazzio, Research Chemist Room M9124	TO	R. K. Soberman Room M9509
------	--	----	------------------------------

DATE SENT	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
9/20/72			

SUBJECT
DEVELOPMENT OF LIGHTWEIGHT THERMALLY STABLE MIRRORS

## INFORMATION REQUESTED/RELEASED

### OBJECTIVE

The objective of this program is to develop material and structural elements which are dimensionally stable when exposed to variable thermal environments.

### I INTRODUCTION

Carbon fibers have nearly zero to slightly negative thermal expansion parallel to their major axis. Thus when they are used as reinforcements to impart high strength and stiffness to resins, they also impart thermal stability at low density in properly designed and fabricated structures. A particularly important application in which to achieve these benefits is in optical surfaces and related structures which must withstand severe temperature extremes.

The Space Sciences Laboratory has been engaged in demonstrating the feasibility of two approaches to these applications over the past year-and-a-half. Our first approach applies to a small (15-20 cm) diameter mirror while the later design should be useful for larger sizes. Both an analytical and an experimental approach has been pursued to demonstrate the feasibility of these concepts. It is necessary however to fill in some aspects of the work to extend it to such areas as other environmental and functional tests, further reducing the weight. The fabricated 15-20 cm diameter carbon fiber/epoxy resin composite mirrors including up to four mils of metallic reflecting surface weigh just under 0.7 gm/cm<sup>2</sup>. While the weight might still be reduced a little by reducing the metallic surface thickness to about two mils, this construction is not amenable to large diameter mirrors of comparable stiffness. Therefore the combined honeycomb core/carbon reinforced resin composites are a more attractive approach. They are currently estimated to weigh 1 gram/cm<sup>2</sup> for a 40 cm diameter mirror. This weight can probably be reduced by about 30 percent with materials and process improvements.

	PAGE NO.  1 OF 7	RETENTION REQUIREMENTS	
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		<input type="checkbox"/> 1 MO.	<input type="checkbox"/> 3 MOS.
		<input type="checkbox"/> 3 MOS.	<input type="checkbox"/> 6 MOS.
		<input type="checkbox"/> 6 MOS.	<input type="checkbox"/> 12 MOS.
		<input type="checkbox"/> MOS.	<input type="checkbox"/> MOS.
		<input type="checkbox"/>	<input type="checkbox"/> DO NOT DESTROY

## II. DESIGN PARAMETERS

It has been shown by Hill<sup>(1)</sup> that bounds on composite modulus can be described in terms of the properties of the constituents. Expressions for thermal coefficients have been developed by Schapery<sup>(2)</sup>, in a similar manner. Using these expressions we find that carbon fibers in epoxy are very attractive from the standpoint of strength, stiffness and thermal response in the fiber direction. However, the properties transverse to the fiber axis are governed primarily by the epoxy matrix and therefore combinations of fiber orientations in a laminate are necessary to obtain a thermally stable composite. It can be shown that certain symmetric ply combinations possess polar symmetry of the thermal expansion coefficient and that the value of  $\alpha$  for the composite approaches that of the fibers.

Since the thermal stability is achieved through the constraint which each  $0^\circ$  ply gives to each  $90^\circ$  ply, internal stresses between plies are developed during fabrication, as well as during thermal excursions in service. High strength and long term dimensional stability are therefore necessary to guarantee continued reliable performance.

One major advantage of the composite approach to lightweight structures is the ability to lay up prepregged tape on a reflector which is electroplated or vapor-deposited on a lens or master tool. This eliminates the need for expensive machining and polishing operations which contribute so heavily to the cost of conventional mirrors. Although the concept is simple there are still numerous details in the fabrication process which must be worked out before the process can be used reliably and reproducibly. The following section describes the fabrication process used for the small diameter mirrors and made from composite substrates and demonstration mirrors made from filled honeycomb substrates.

## III. FABRICATION

Twenty cm diameter mirrors were designed and fabricated to test the feasibility of the approach described above. First, model systems of 3M Scotchply (glass/epoxy) were fabricated according to various fiber and ply layup orientations. Both flat panels (6" x 6" x various thickness) and parabolic shapes were fabricated using the hand layup of prepreg tape/vacuum bag cure technique. The Scotchply prepreg tape is made of unidirectionally oriented glass fibers in an epoxy matrix. The tape was trimmed to the length and width required to assume the radius of curvature. Layers were then laid up according to the orientations described earlier; a vacuum bag was used to cover the layup and the assembly was cured for three hours at  $300^\circ\text{F}$ . Flat laminates both unidirec-

---

(1) Hill, R., "Theory of Mechanical Properties of Fiber-Strengthened Materials of Arbitrary Transverse Phase Geometry," J. Mechan. Phys. Solids, Vol. 12 (1964), p. 199.

(2) Schapery, R. A., "Thermal Expansion Coefficients of Composite Materials Based on Energy Principles," J. Comp. Mat. 2, 380 (1968).

tionally and ply oriented were cured the same way. All configurations showed no sign of warping or distortion after six months standing at 77°F and 55% R. H.

The carbon/epoxy system was then fabricated by the same technique in the same configuration as the glass. The carbon/epoxy system selected for the demonstration units was high-modulus fiber in BP-907-u modified epoxy. The prepreg was supplied by Hercules, Incorporated. Individual constituent and composite properties of this system are shown in Table 1.

After curing the composite parabolic shape on a glass master, the composite was removed. The master was solvent cleaned and a gold reflector was vapor deposited to it. Both the back of the reflector and the adjoining composite surfaces were prepared for bonding. Epoxy adhesive was painted over the metal surface and the two mating surfaces were put together. The assembly was removed from the master.

Other mirrors were prepared by the same curing technique except that the prepreg tape was laid up over an epoxy adhesive coated reflector so that the bonding and composite curing took place simultaneously. Both techniques showed to be equally effective to join the composite backing to the reflecting surface. Figure 1 shows a finished mirror made by the latter technique.

This study demonstrated the following points:

- (1) Good quality reflecting surfaces of silver, gold and nickel could be uniformly deposited on a master lens to which a parting agent had been applied to facilitate removal.
- (2) Various ply orientations of carbon/epoxy prepreg can be easily applied to a curved surface if care is taken to prevent discontinuities or ripples.
- (3) The curing procedure must be carried out under low pressure conditions with sufficient resin at the fiber/reflector interface to prevent the fibers from being pressed into the reflector.

Although the optical quality of the first mirror (wt. 120 gm) was not as good as had been hoped for, the results were explainable and encouraging. None the less our needs for larger mirrors (> 20 cm) with even more severe weight limitations dictated a new approach. For these mirrors a honeycomb configuration was selected with the reflector forming the front skin and the rear skin to be a carbon/epoxy laminate.

Lightweight Aluminum honeycomb constructed from 1.5 mil thick film, into 1/8" cells, having a core density of 4.5 lbs/ft<sup>3</sup> was used as part of the light weight composite backing. In order to provide the necessary stiffness for machining a curved surface, to which the mirror surface will be bonded, the cells were filled with phenolic microballoon spheres in epoxy resin. The density of the filler material will be approximately 8.0 lbs/ft<sup>3</sup>. In the interest of saving weight it was planned to fill the cells deep enough to obtain

TABLE 1

## CONSTITUENT AND COMPOSITE PROPERTIES OF A CARBON/EPOXY SYSTEM (2002M)

	HM-S Fibers	Epoxy Resin BP-907-U	Prepreg	Composite (unidirectional)	Composite (0°, 90°, -45°, +45°) <sub>2</sub>
Density, lbs./in <sup>3</sup>	0.070	0.043	-		
Specific Gravity	1.94	1.2	-	1.56	1.50
Tensile Strength, x 10 <sup>3</sup> psi	250-240	7-9	-	> 106.5	35.5
Tensile Mod., x 10 <sup>6</sup> psi	56	0.45	-	22.2	7.2
Coefficient of Thermal Expansion (10 <sup>-6</sup> /in/in/°F)	$\frac{+}{-} .3$	.46-.55	-	-	-
Flexural Str. x 10 <sup>3</sup> psi	-	-	-	133.0	54.0
Flexural Mod. x 10 <sup>6</sup> psi	-	-	-	25.3	13.2
Resin Content, % wt.	-	-	42 $\frac{+}{-}$ 2	40	40.5
Fiber Content, % wt.	-	-	58	-	-
Flow, %	-	-	3.2	-	-
Volatiles, %	-	-	1.0	-	-



a uniform curved face surface for bonding, and to assure that none of the cell edges bear through the reflected surface.

A light weight face sheet made of carbon fiber-epoxy warp sheet (unidirectional staple fiber prepreg) oriented in such a way as to provide the polar symmetry and low coefficient of linear expansion needed in mirror applications, would be bonded to the opposite side of the composite mirror. The total composite-mirror assembly should provide as stable an optical system as is presently available but of considerably lighter weight.

In this study work was completed only to the mirror/honeycomb combination because of the problems encountered with optical quality. Figure 2 shows the optical quality of the mirror. The mirror stands endwise on a lined paper to show up any distortion. Note that the upper left hand section of the mirror is distorted. This was caused by a void left between honeycomb and reflecting surface (resin flowout). The situation can be controlled by placing a dam around all sides of the assembly for curing purposes. The 4" x 4" mirrors which were made were tested for optical quality by using a collimated beam from a He-Ne laser played on the surface and the far field diffraction pattern observed. The mirrors were not considered optical quality, however, most of the surface is regular to about 2-3 wave per inch. It is evident that more work is needed to improve the optical quality of the mirrors. The problems as seen from the work completed to date indicate that high quality is not difficult to achieve.

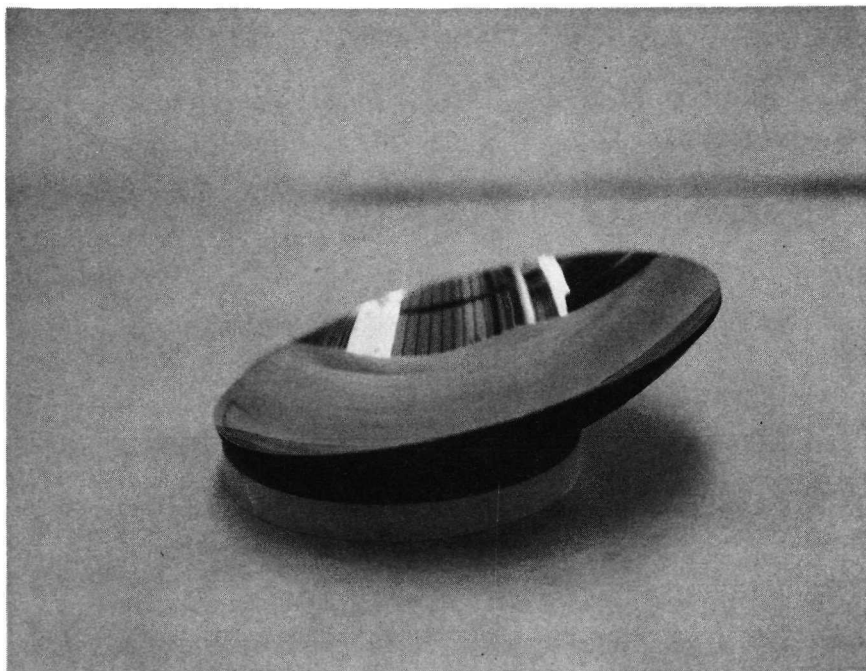


Figure 1. Carbon/Epoxy Composite Mirror.

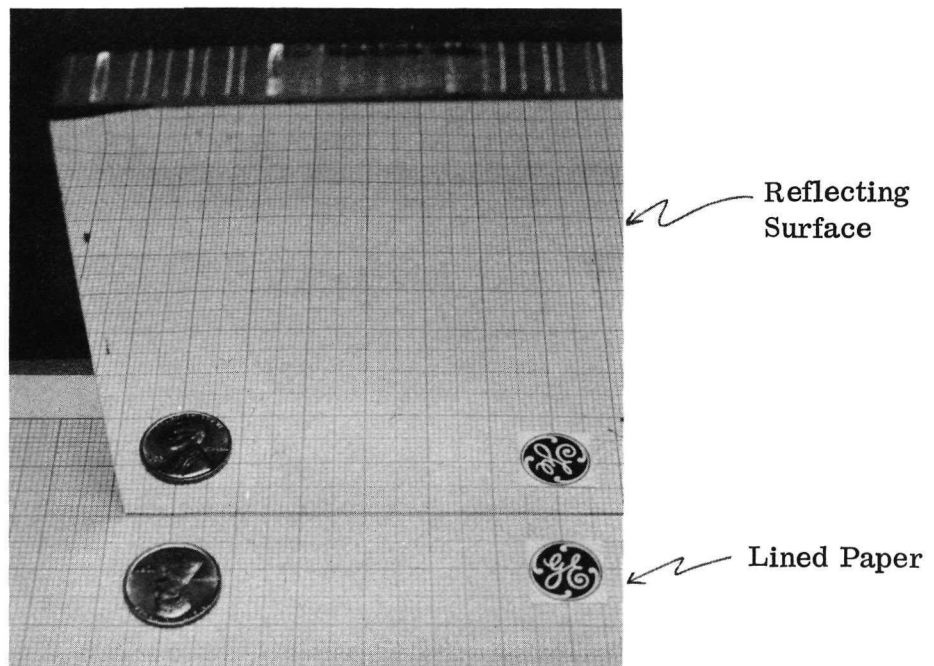


Figure 2. Honeycomb Filled with Phenolic Microballoons in Epoxy with a Reflecting Surface - Standing Edgewise on Lined Paper to Show Optical Quality.

## APPENDIX F

**PROGRAM INFORMATION REQUEST / RELEASE**

PIR NO.	*CLASS. LTR. U	OPERATION 1271	PROGRAM	SEQUENCE NO. 669	REV. LTR.
*USE "C" FOR CLASSIFIED AND "U" FOR UNCLASSIFIED					

FROM H. W. Halsey	TO R. K. Soberman, Manager Meteor and Planetary Physics
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DATE SENT 8/30/72	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
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SUBJECT  RETESTING OF ITT PHOTOMULTIPLIER TUBES
INFORMATION REQUESTED/RELEASED

INTRODUCTION

Two ITT Photomultiplier tubes with special entrance window material were received and tested in October 1971. The result of the initial tests were published in PIR 2153-003, dated October 26, 1971. The tubes were tested for: (a) Anode dark current as a function of overall applied voltage, (b) Gain as a function of overall applied voltage, (c) Anode sensitivity of the tube as compared to another photomultiplier tube and (d) The tubes were scanned to obtain a sensitivity map of the photo-cathode.

The tubes were then placed in a nuclear reactor and given  $10^6$  Rads over a period of 6 months. The tubes were then retested as before and the results of the tests are given below. The same socket and biasing circuit were used in both test periods.

DATA

A. Anode Dark Current

The anode dark current of the two tubes was measured as a function of overall voltage. The result of this test is shown in the graphs of Figure 1 and Figure 2. Also plotted on the same graph is the dark current data taken in October 1971 and by ITT before the tubes were shipped.

B. Gain as a Function of Applied Voltage

The gains of the two tubes were measured as a function of applied voltage. These data are plotted in the graphs of Figure 4 and Figure 5. Also plotted on the same graphs are the results of the gain measurement made in October 1971.

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## PIR

### C. Anode Sensitivity

The anode sensitivity of the two tubes was compared with an RCA SEL 7265 S/N K06062 which was stored in the dark between the two tests. The tubes were tested both times in exactly the same way. Each tube had 1500 volts across it. The ITT tubes used the bias network shown in the data sheets with  $R = 82K$  while the SEL 7265 used the bias network which is permanently soldered to its base. The data on these networks are contained in H. Halsey's record book #2-25-66 on page 61ff.

The ratios of the anode sensitivities of the three tubes are given below:

<u>Tube</u>	<u>S/N</u>	<u>Sensitivity Ratio Before Exposure</u>	<u>Sensitivity Ratio After Exposure</u>
F71-0914A	097101	8.56	2.72
F91-0914	09710	8.56	3.65
SEL 7265	K06062	1	1

### D. Sensitivity Map of Photocathode

The tube faces were scanned using a 24 inch diameter scanning disk which had 36 scanning holes each 0.1 inch in diameter, on a 20 inch diameter for the first hole. Succeeding hole centers were spaced 0.1 inch closer to the center of the disk. The disk was rotated at 1 rpm. The tube face was placed 0.3 inches behind the scanning disk. The light source, which was a number 1819 pilot lamp was placed 51 inches in front of the scanning disk. The entire assembly was placed in a light tight box. The lamp was operated at 26.71 volts dc from a regulated supply. The data was recorded on a Honeywell model 1508 Visicorder.

## SUMMARY

The results of each test are summarized below.

### A. Anode Dark Current

The anode dark current of both tubes dropped slightly after exposure.

B. Tube Gain

The gain of both tubes dropped after exposure. The gain of S/N 097103 dropped only slightly. The amount of change was about equal to the measurement error. The gain of S/N 097101, however, dropped by slightly more than two decades after exposure to radiation.

C. Anode Sensitivity

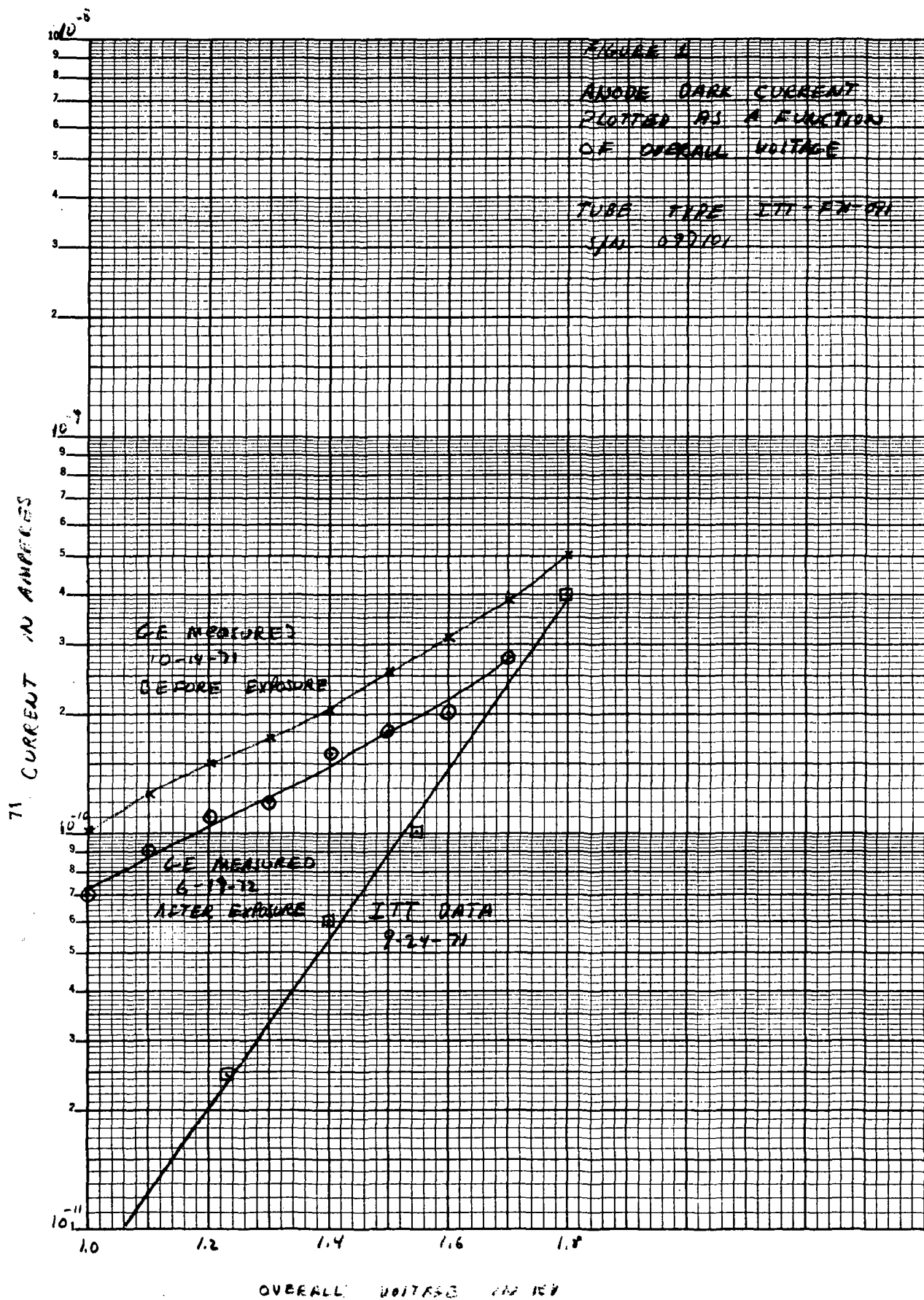
The anode sensitivity of both tubes dropped after exposure to radiation. Tube number 097101 dropped in sensitivity by more than a factor of 3 while tube number 097103 dropped in sensitivity by slightly more than a factor of two.

D. Sensitivity Maps of Photocathodes

No changes were observed in the sensitivity map of the photocathodes.

When the two tubes were first tested after exposure to radiation it was found that tube number 097101 was inoperative. After a sharp blow with a 3/8 inch diameter lucite rod, with voltage applied to the tube, the tube began to operate. At the time of the blow a visible arc was seen inside the tube.

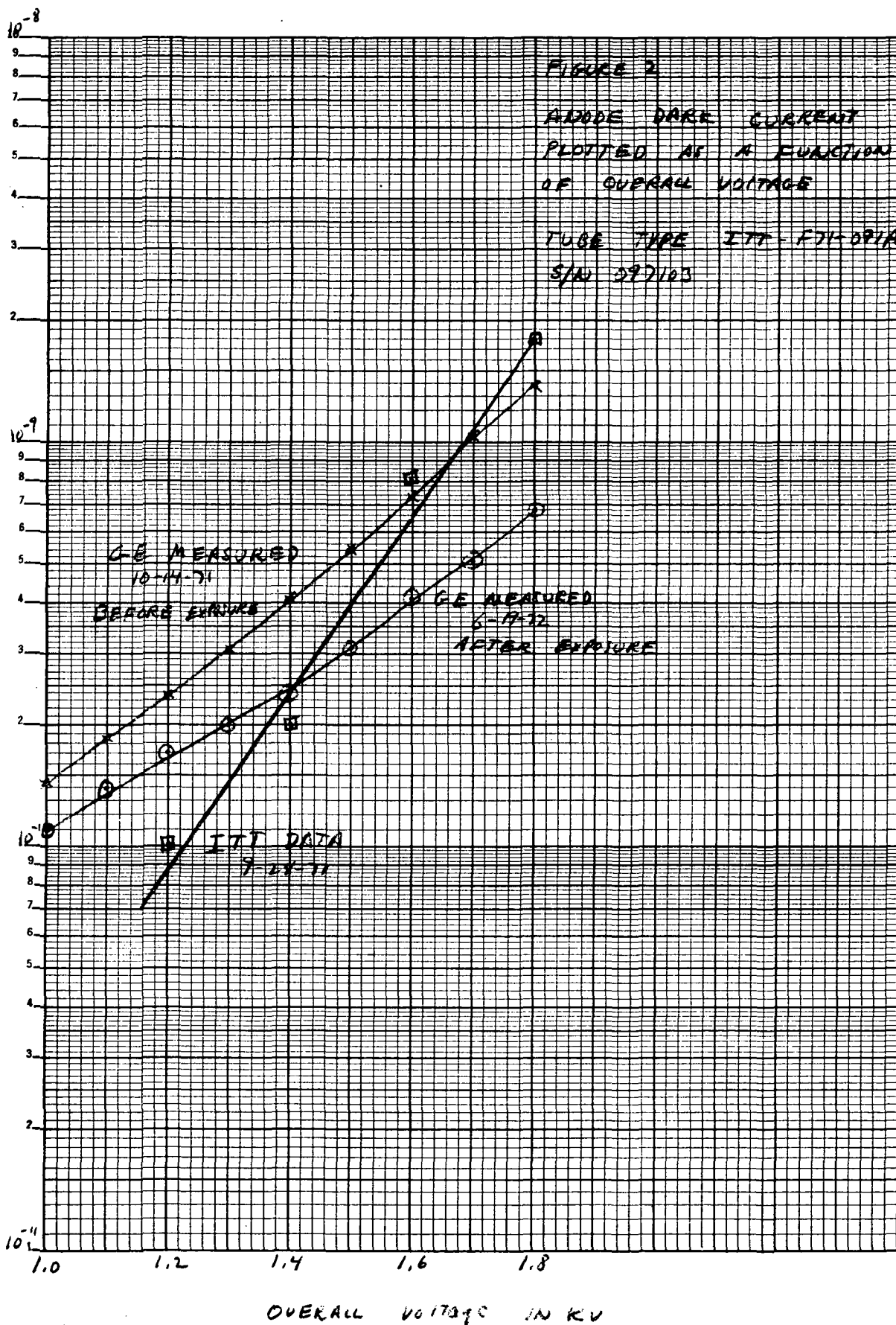
In addition it was determined that no visible darkening of either the glass envelope or the tube windows had occurred during exposure to the radiation.





CURRENT IN AMPIERES

71



TUBE GAIN

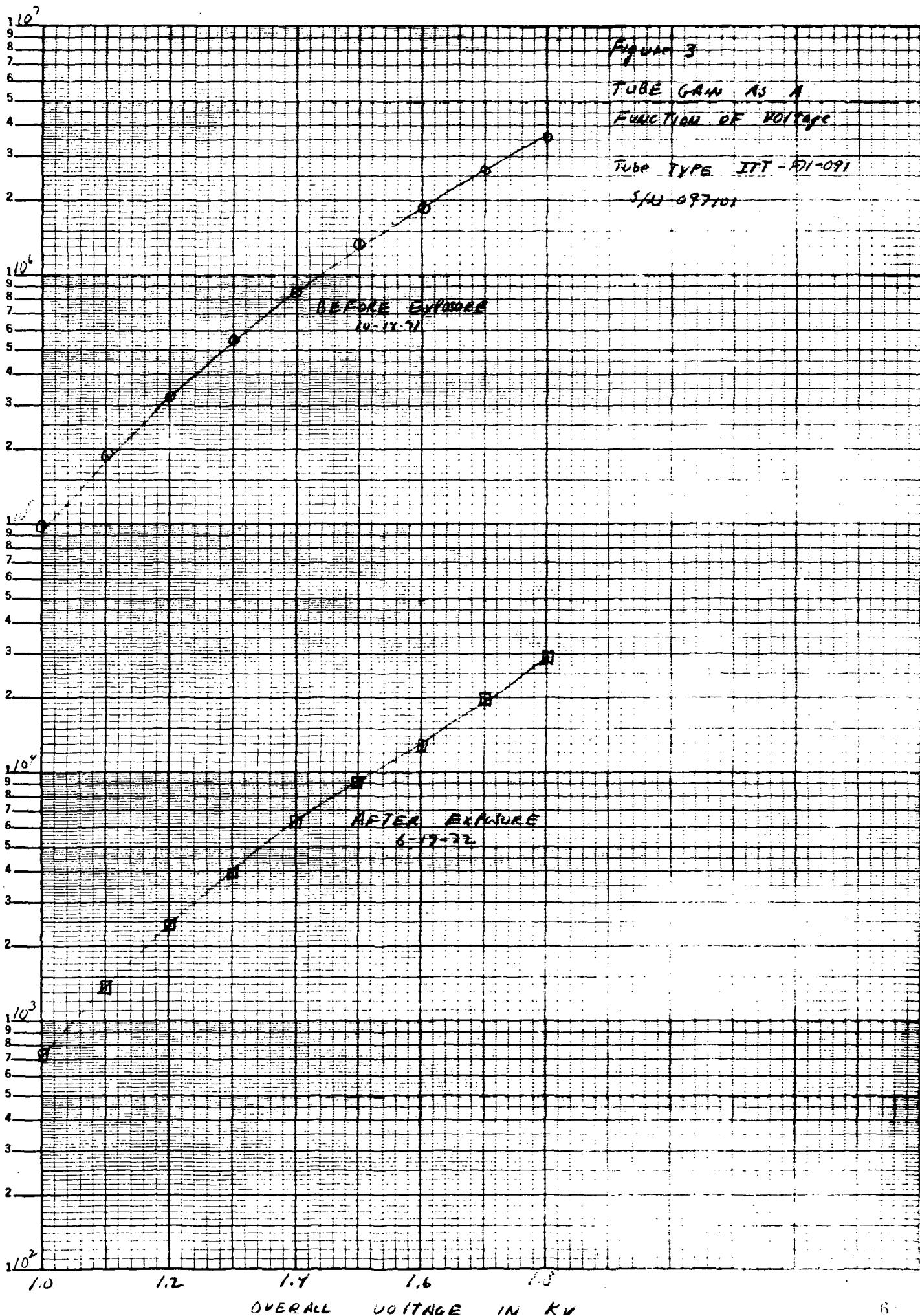


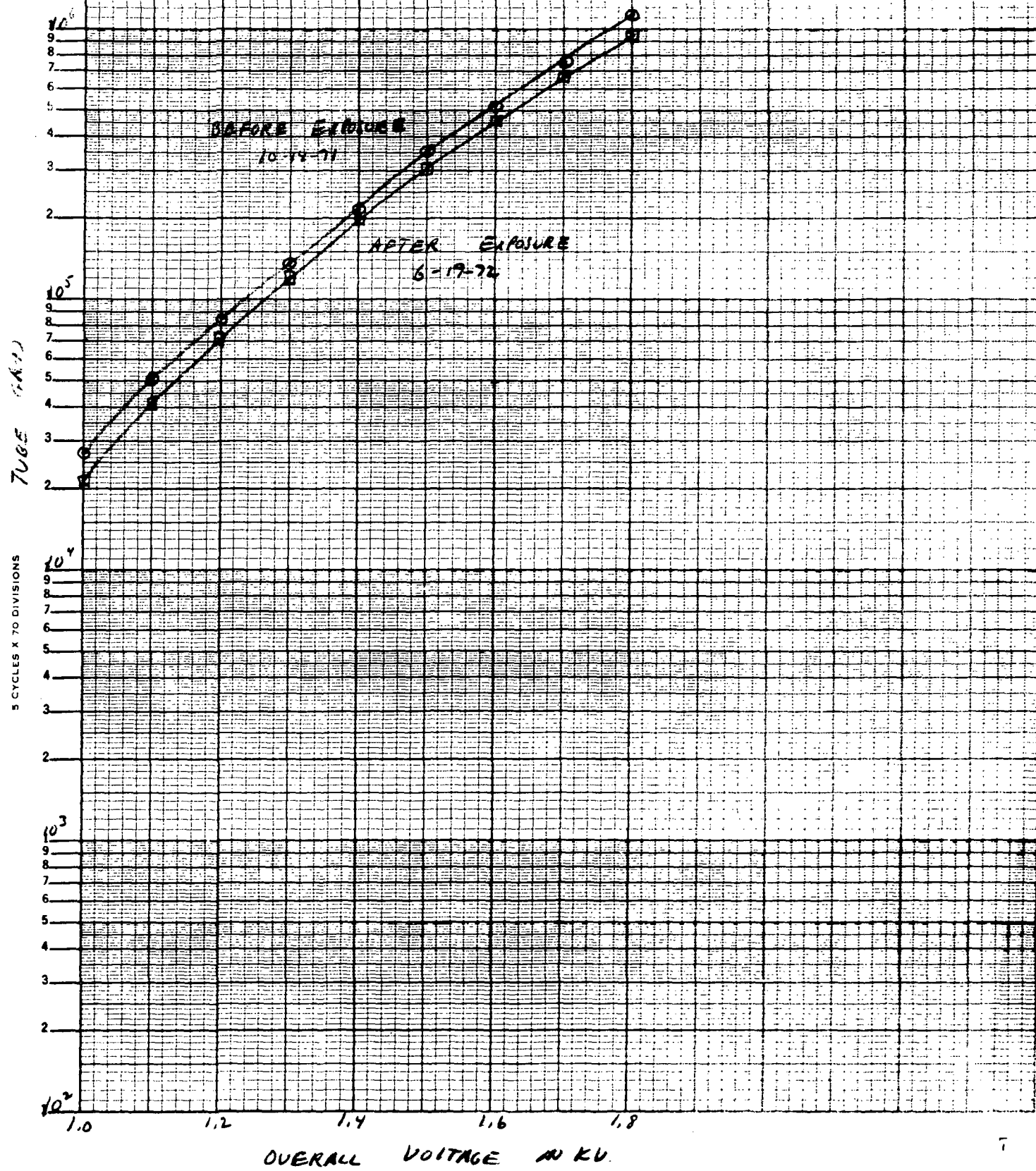
FIGURE 4

TUBE GAIN AS A

FUNCTION OF VOLTAGE

TUBE TYPE 1TT-A21-091A

S/N 097103



## APPENDIX G

# INVESTIGATION OF THE LIGHT EMISSION DURING IMPACT OF ENERGY CHARGED MICROPARTICLES

Thesis to obtain M. Sc. Degree (Dipl. -Ing.)

by

G. Eichhorn

Max-Planck-Institut für Kernphysik  
Heidelberg 1972

## Summary:

This report analyses the light emission of impacting microparticles and presents the results with emphasis on establishing basic data for future spacecraft experiments.

Typical factors for the light emission are:

1. The duration of the emitting light,
2. The intensity of the integrated signal,
3. The intensity of the first peak, and
4. The intensity of the second peak.

The relationship of mass and particle speed follows the form of

$$I = C \cdot M^{\alpha} \cdot V^{\beta}$$

whereby only the constant  $C$  depends on the target material,  $\alpha$  and  $\beta$  are nearly independent.

This is valid for gold and tungsten. It can be assumed that  $\alpha$  and  $\beta$  will have similar values for other target metals, since gold and tungsten show vastly different conditions with respect to the form of the light flash. Only the duration of the light emission depends on the target material. For gold as target is

$$D = C_o \cdot V^{\beta_o} \quad C_o = 2.20 \cdot 10^2$$
$$\beta_o = -0.4$$

For tungsten is  $C_o = 9.84 \cdot 10^2$  and  $\beta_o = -1.18$ . The duration of the light flash is independent from the particle mass, and from its measurement it is possible to determine the velocity. All other measured parameters are affected by mass and velocity.

The intensity of the first peak is

$$I_1 = C_1 \cdot M^{\alpha_1} \cdot V^{\beta_1} \quad \alpha_1 = 1.24 \pm 0.05$$

$$\beta_1 = 4.9 \pm 0.2$$

The intensity of the second peak is

$$I_2 = C_2 \cdot M^{\alpha_2} \cdot V^{\beta_2} \quad \alpha_2 = 1.22 \pm 0.05$$

$$\beta_2 = 4.3 \pm 0.2$$

The intensity of the integrated signal is

$$I_3 = C_3 \cdot M^{\alpha_3} \cdot V^{\beta_3} \quad \alpha_3 = 1.26 \pm 0.05$$

$$\beta_3 = 3.75 \pm 0.2$$

For gold as target material is

$$C_3 = 5.50 \cdot 10^7 \text{ erg/g}^{1.25} \cdot (\text{Km/sec})^{3.75}$$

and the Intensity

$$I_{\text{gold}} = 5.50 \cdot 10^7 \cdot m^{1.25} \cdot V^{3.75} [\text{erg}]$$

where  $m$  is measured in  $[g]$  and

$V$  is measured in  $[\text{Km/sec}]$ .

The measured values for  $\alpha_1$ ,  $\alpha_2$  and  $\alpha_3$  are approximately  $\alpha = 1.25$ , and for  $\beta$  the results showed different values. The constants  $C_1$ ,  $C_2$  and  $C_3$  basically depend on the target material and the sensitivity and amplification of the photomultiplier, which would require a calibration for each space flight application.

Because of the four useful parameters a good redundancy is available with gold as target material which appears to be best suited for satellite experiments. All other target materials have relatively low intensities with the exception of W, Ta, Re and Mo which show high intensities but are short by one data parameter. Only Pt yields a higher intensity but has a poor separation between first and second peak.

The validity of measurements ranges for a particle velocity between 1 to 30 Km/sec. Extrapolations are possible only for higher velocities, because for speeds below 0.8 Km/sec the generated charge is greatly reduced. Since at least the first part of the light flash is correlated to the plasma, changes of the light emission would most likely occur within this velocity range. < 0.8 Km/sec.

The possibility to determine M and V using four measurable values seems to provide a convenient method for registration of microparticles during satellite missions especially in interstellar space.

#### Tabulation 2

Target-Material	Al	Ga	Bi	Sn	Pb	Ag	Cu	Fe	Ni	Pyrex	Au	Pt
Intensity	1	1,6	2,7	3,0	3,8	3,8	4,5	7,5	16	19	24	43
Melting Point °C	659	30	271	232	327	961	1083	1540	1460		1065	1770
Target-Material	Mo	Re	Ta	W								
Intensity	230	520	680	750								
Melting Point °C	2620	3180	2996	3390								

Bild 17: Pulsdauer vs. Masse  
Au-Target

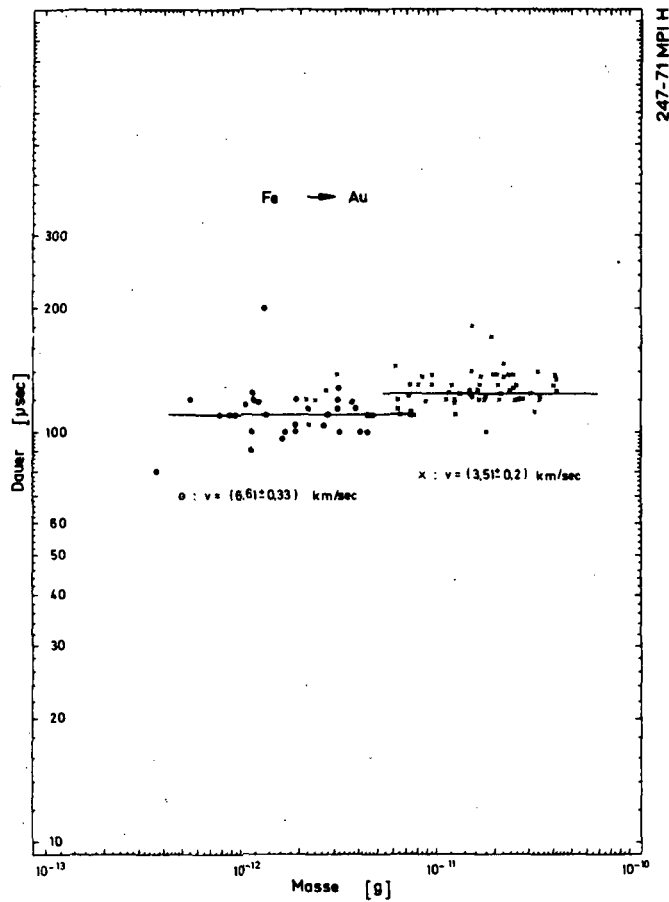


Bild 18: Pulsdauer vs. Geschwindigkeit  
Au-Target

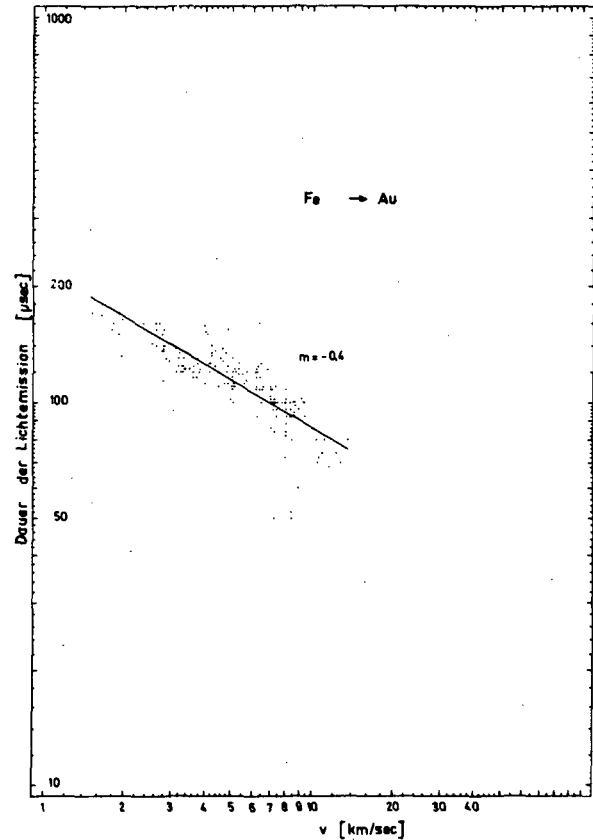


Bild 19: Pulsdauer vs. Masse  
W-Target

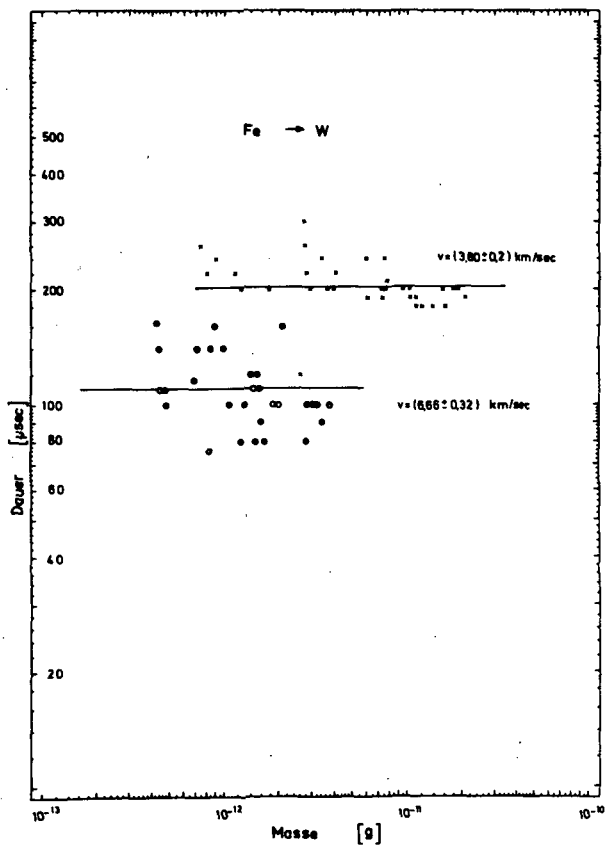


Bild 20: Pulsdauer vs. Geschwindigkeit  
W-Target

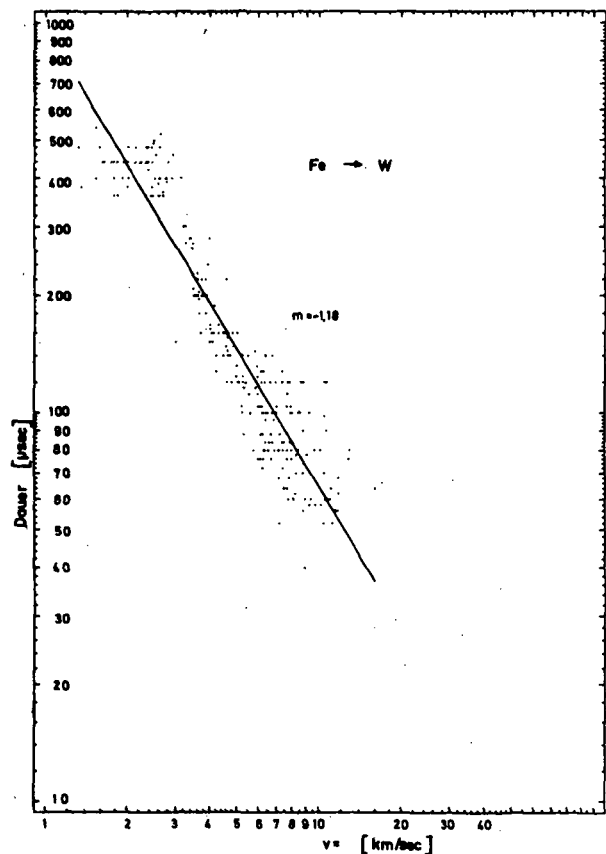




Bild 24

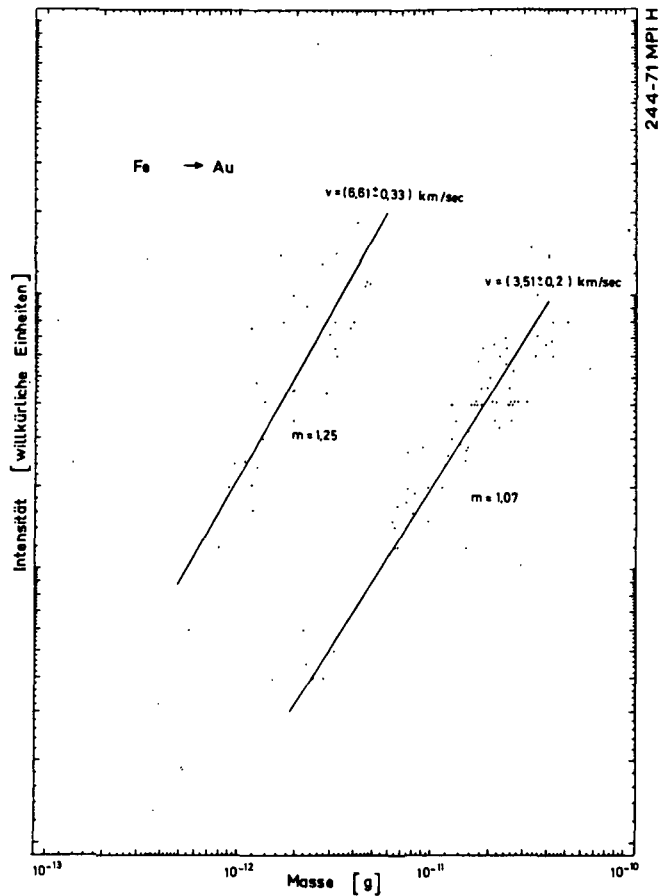


Bild 25

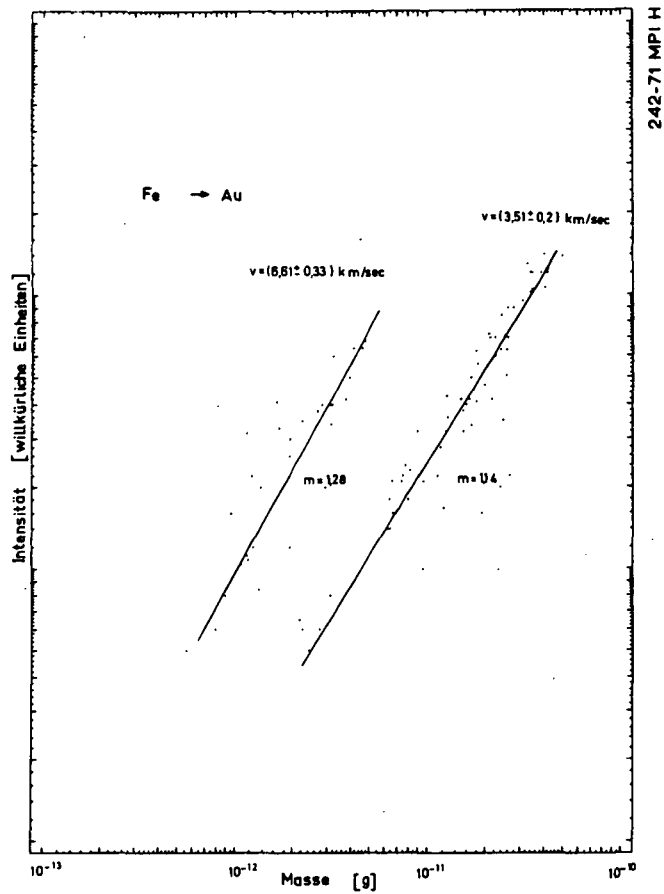


Bild 26

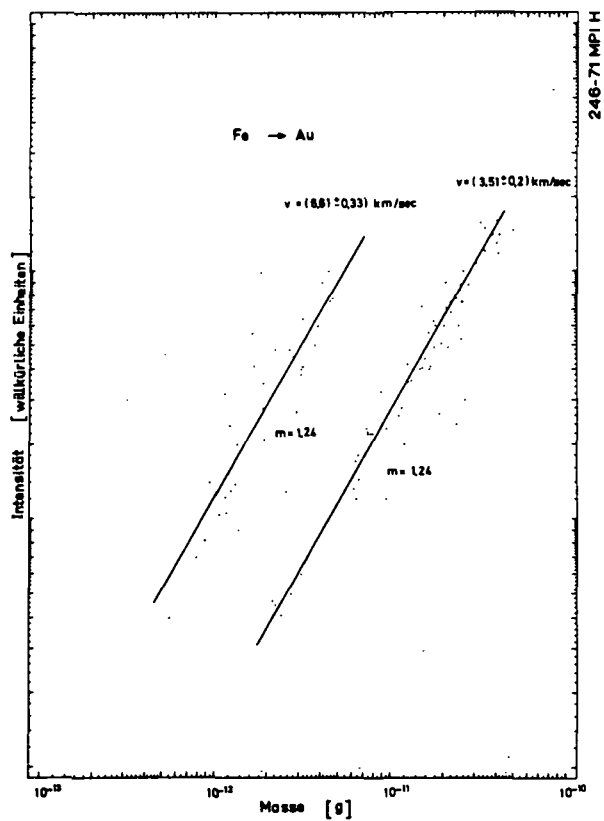


Bild 24: Intensität des 1.Peak  
vs. Masse

Bild 25: Intensität des 2.Peak  
vs. Masse

Bild 26: Intensität des integrier-  
ten Lichts vs. Masse

Bild 27: Intensität des 1. Peak  
vs. Masse

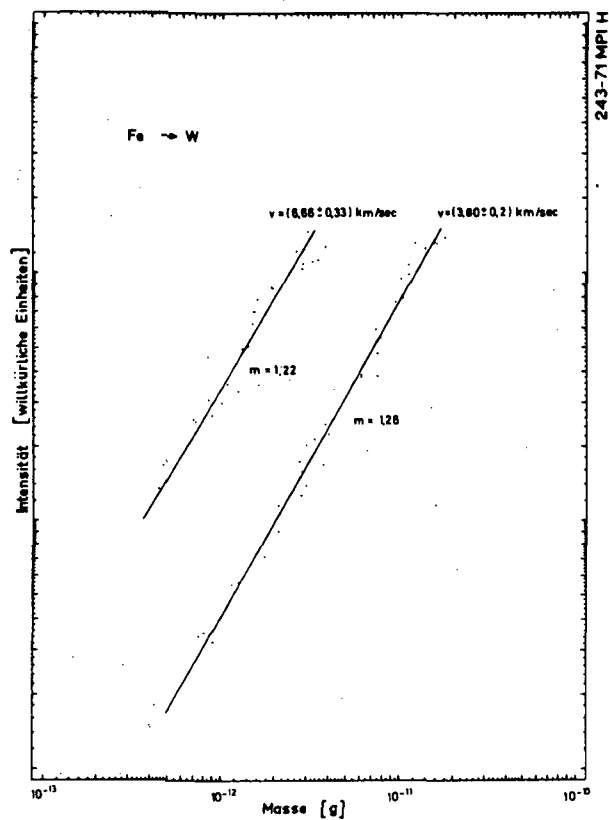


Bild 28: Intensität des integrierten  
Lichts vs. Masse

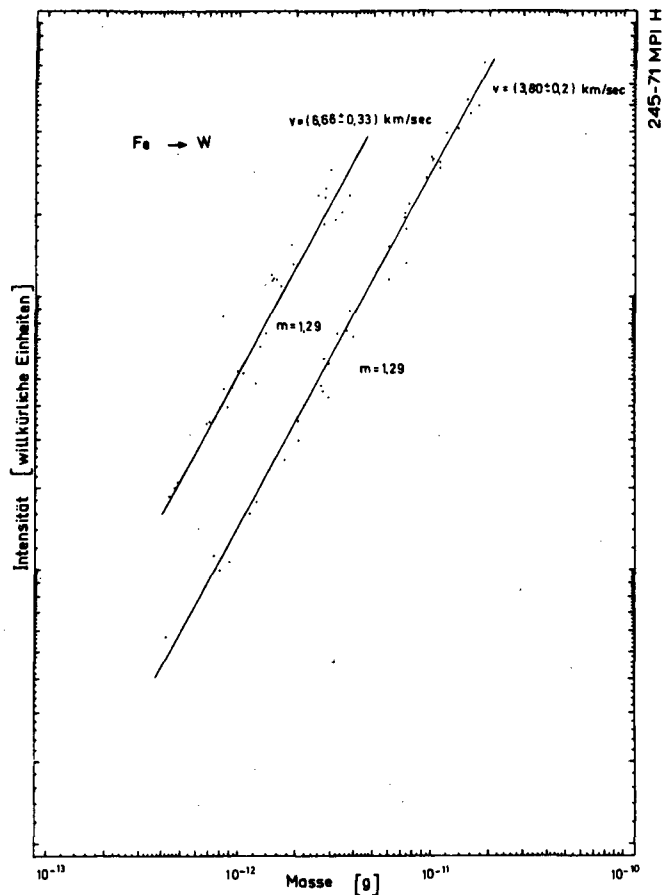


Bild 29: Intensität des integrierten  
Lichts vs. Geschwindigkeit

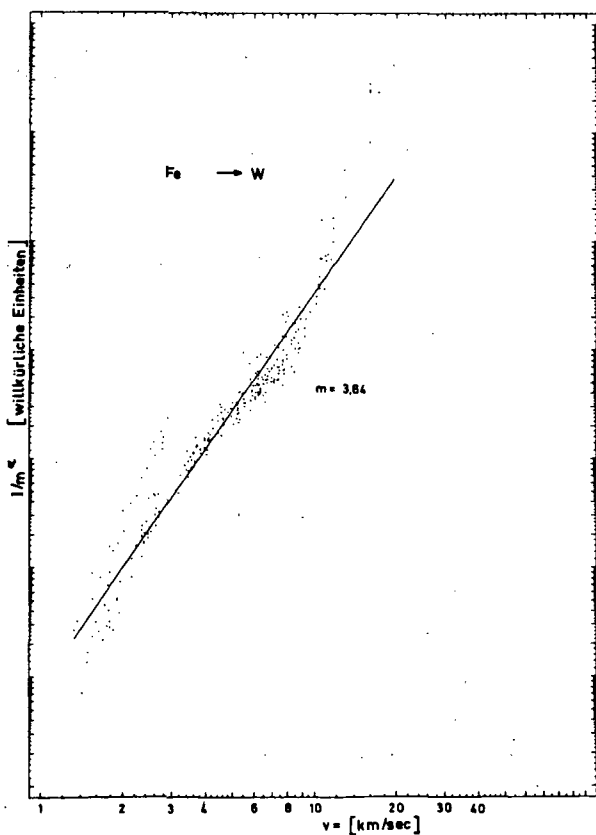


Bild 30: Intensität des 1. Peak  
vs. Geschwindigkeit

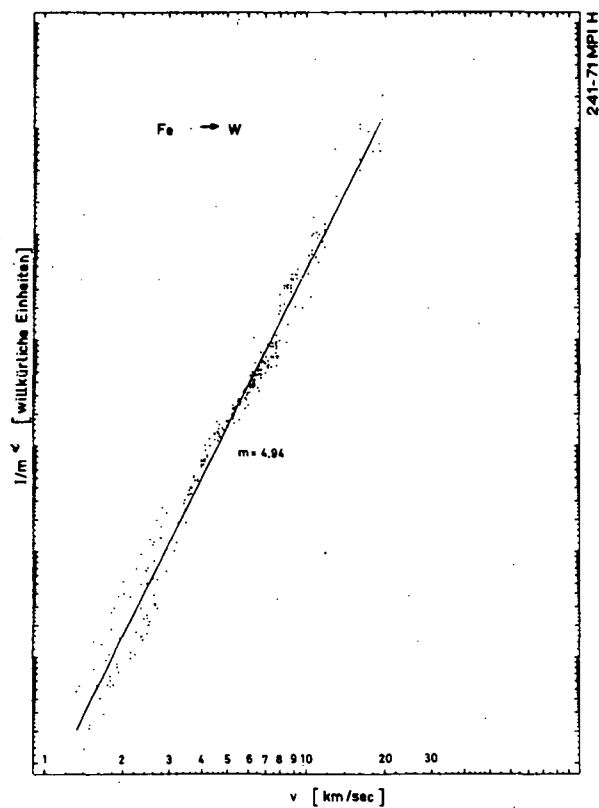


Bild 31

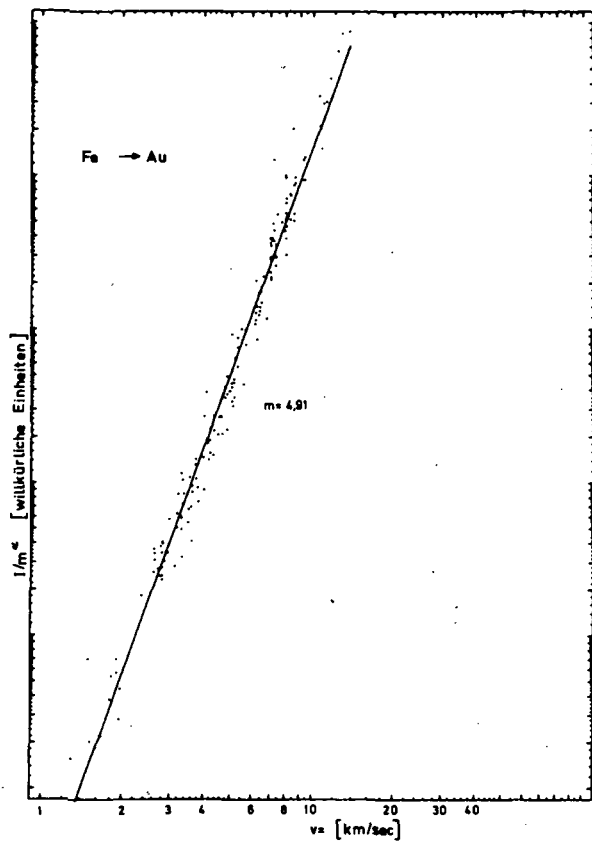


Bild 32

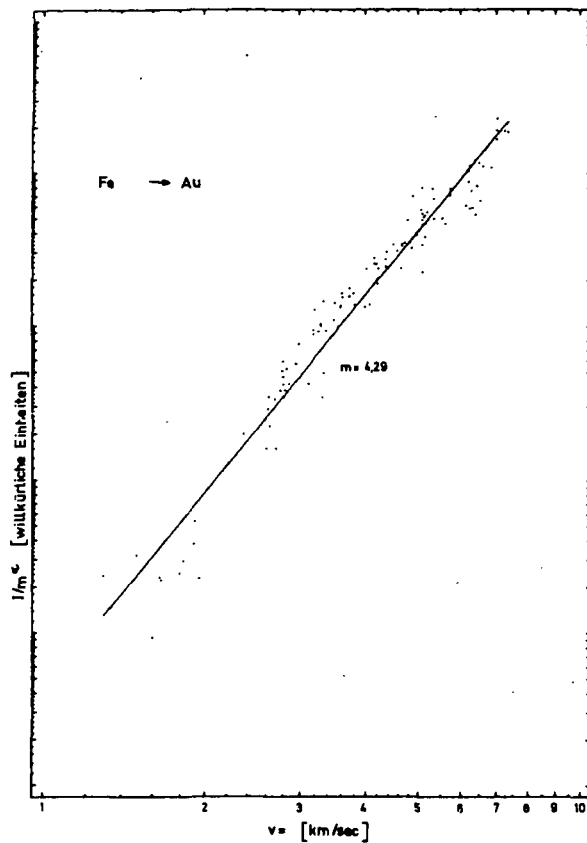


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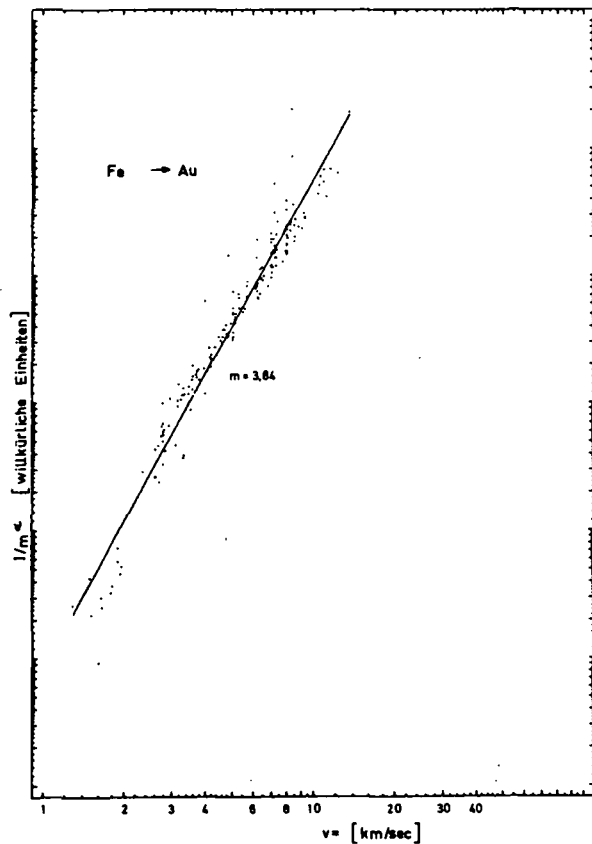


Bild 31: Intensität des  
1. Peak vs. Ge-  
schwindigkeit

Bild 32: Intensität des 2.  
Peak vs. Geschwin-  
digkeit

Bild 33: Intensität des in-  
tegrierten Lichts  
vs. Geschwindig-  
keit

Bild 34

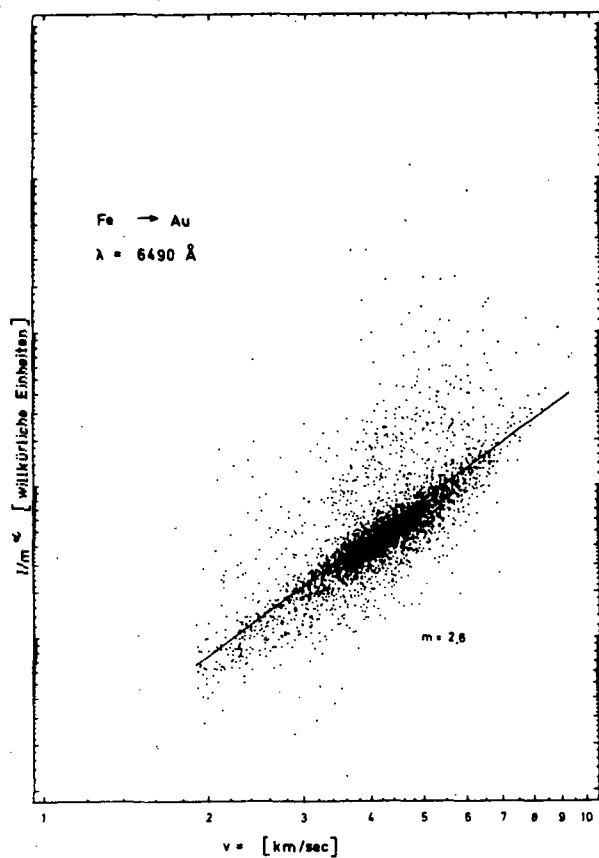


Bild 35

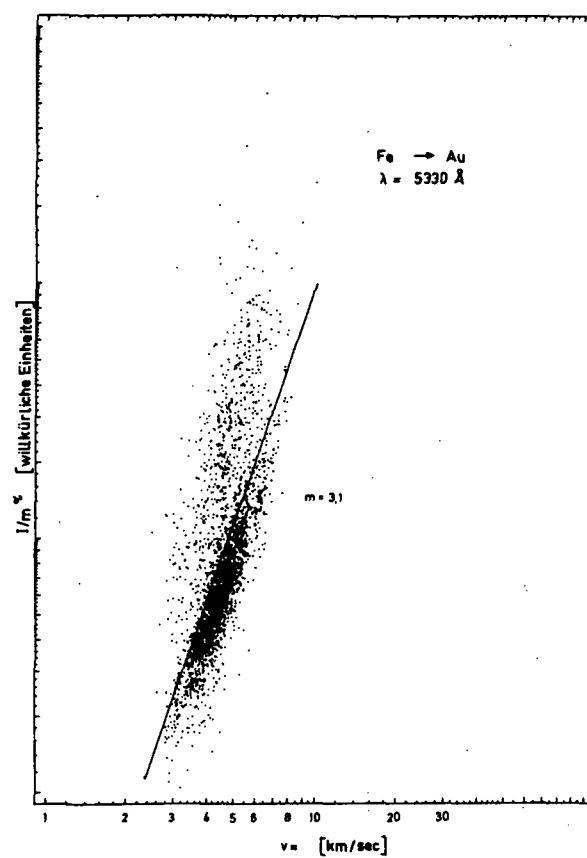


Bild 36

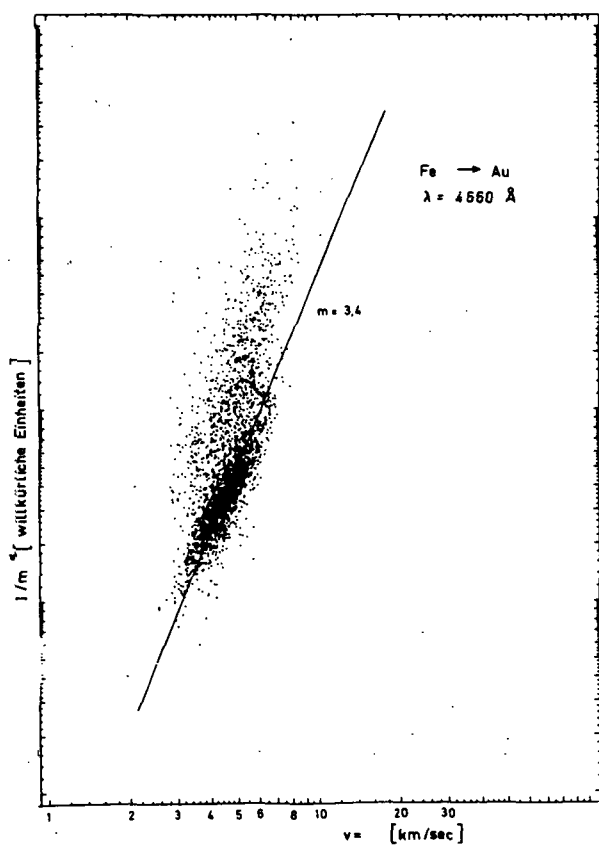


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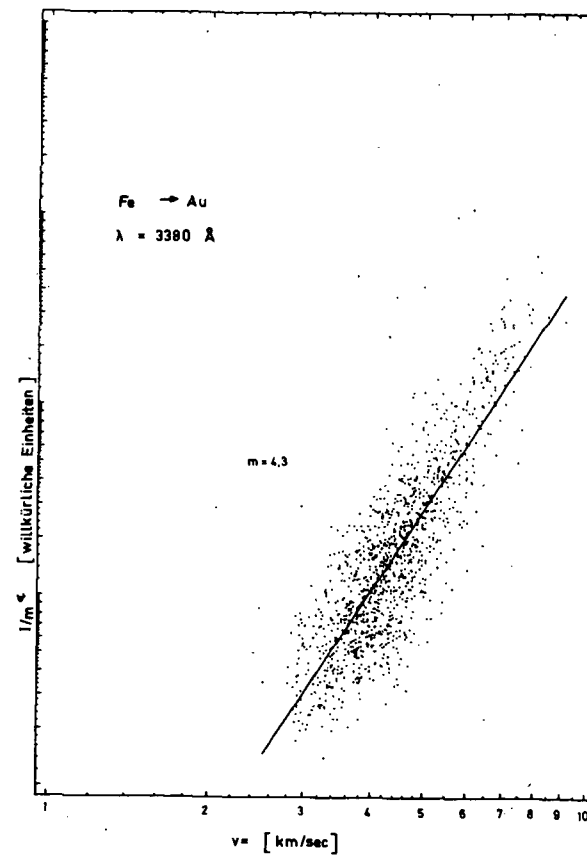


Bild 38

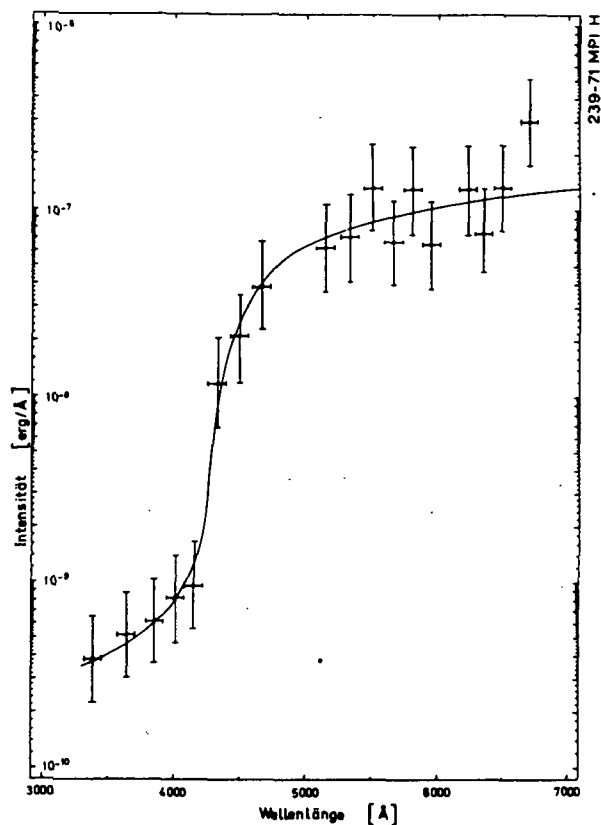


Bild 39

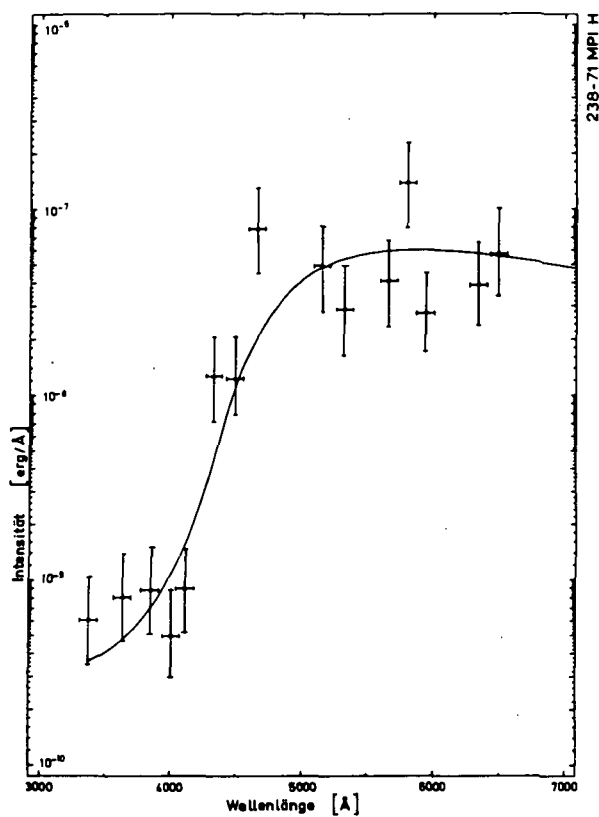


Bild 40

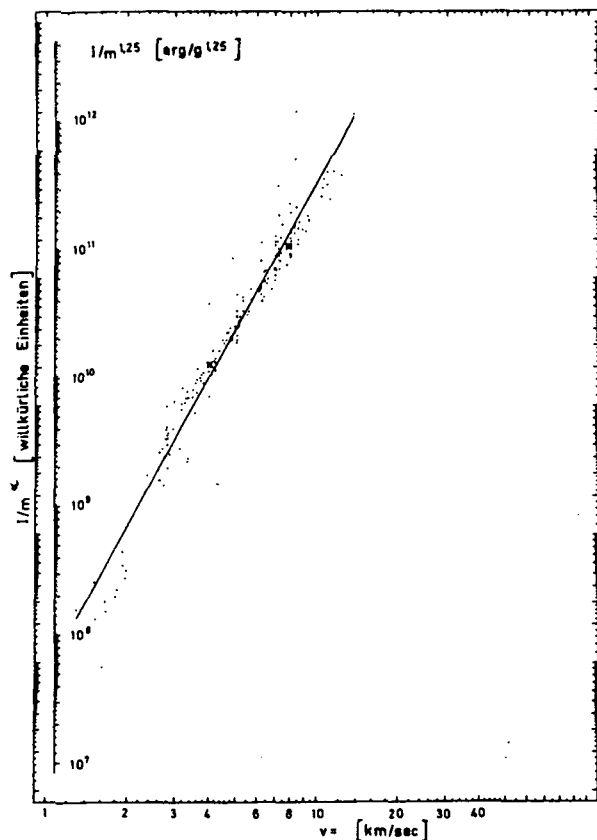


Bild 38: Spektrale Verteilung  
der Lichtintensität  
bei  $v = 4,05$  km/sec

Bild 39: Spektrale Verteilung  
der Lichtintensität  
bei  $v = 7,95$  km/sec

Bild 40: Wie Bild 33, mit ab-  
soluter Skala laut  
3.4., Seite 30

## APPENDIX H

## APPENDIX H

### SELECTION OF POINTING ANGLES

ILLAD is a combination of detectors designed with particular emphasis on measurements of five different types of particles which are expected to be encountered on the Earth-Jupiter-Saturn-beyond flight. Four of the units require impact and a fifth varies in its sensitivity with direction of pointing. The first is a high sensitivity particle impact ionization detector of about  $100 \text{ cm}^2$  active area [IID(1)] pointing in the -Z direction (towards Earth). A second similar unit of about  $200 \text{ cm}^2$  active area [IID(2)] points at a cone angle (defined below) of about  $100^\circ$ , and  $20^\circ$  to  $30^\circ$  out of the ecliptic. The third unit is a time-of-flight spectrometer (IIMS) which will mass analyze impacting particles. It points about  $30^\circ$  to  $45^\circ$  out of the ecliptic at a cone angle of about  $157^\circ$ . The fourth and fifth are a combined impact flash-acoustic detector and the optical particle detector (Sisyphus). These are incorporated into the same telescopes which point approximately in the same direction as the IIMS (see below).

The pointing directions selected are tentative and really serve only to indicate the feasibility of the location and the possible range of the instrument. As the planned spacecraft trajectory is changed, the different pointing angles will also change. The present instrument orientations are designed to accomodate five different kinds of particles and their various relative velocity vectors.

The five different kinds of particles are listed below. Relative velocity vectors during the Earth-Saturn flight were calculated from the detailed JST trajectory information from the Jet Propulsion Laboratory, and the ring particle vectors from the limited information available on the JST and JSI Saturn swingby trajectories. Velocity vectors are given relative to the spacecraft, with clock angles referred to the ecliptic south pole as 0 clock and cone angles referred to a -Z axis that points toward Earth.

Asteroids (assumed circular heliocentric orbits between 2 and 4 AU):

<u>Magnitude</u>	<u>Clock Angle</u>	<u>Cone Angle</u>
12-20 km/sec	$\sim 90^\circ$ or $270^\circ$	$180^\circ - 160^\circ$

Interplanetary Particles:

Because these particle orbits can vary considerably, it is difficult to specify a given direction. Since there is a tendency for the particles to lie near the ecliptic plane, the instrumentation is designed to cover as much of the ecliptic plane as possible.

Solar Vicinity Particles:

For lack of better information it is assumed that these particles will be within  $45^\circ$  of the sun.

Interstellar Particles (assumed to move parallel to apex of sun's way with an incoming heliocentric velocity of 20 km/sec):

<u>Magnitude</u>	<u>Clock Angle</u>	<u>Cone Angle</u>
~ 90 km/sec	~ 270°	5° - 20°

Ring Particles (assumed circular Saturnocentric orbits):

<u>Magnitude</u>	<u>Clock Angle</u>	<u>Cone Angle</u>
JSI 10.9 km/sec	285°	133°
JST 21.0 km/sec	162°	135°

Figures 1, 2, and 3 are plane projections of a three-dimensional sphere and show the orientations of the particle relative velocity vectors and the axes of the detector units. The grid lines are great circles on the sphere, and each vector is represented as a point on the surface of the sphere, depicting a vector which points to the center of the sphere and intersects the surface at the indicated point. This method of vector-direction display is useful because angles between vectors may be quickly measured, and the different acceptance cones of the instruments can be drawn.

Figure 1 shows the locus of interstellar particle relative velocity vectors and the location of the IID(2) and IID (1). The ecliptic plane is shown horizontal with the north ecliptic pole at the top. The view is toward Earth. The IID(2) axis is shown at Saturn, with an arc to indicate its position at other times in the flight as the spacecraft tracks Canopus. The 45° acceptance cone is ample for the interstellar particles with the axis of the detector at any position on the movement arc. The IID(1) is pointing in the -Z direction, and the 45° acceptance cone is shown as a dashed line to indicate it is on the opposite side of the sphere. Solar particles with cone angles of only 5° to 15° are almost centered in the acceptance cone of this detector.

Figure 2 shows the relative velocity vectors of the asteroids and the ring particles. The view is also towards Earth. Shown too, is the location of the IIMS at Saturn, with an arc to indicate its position at other times in the flight. With the IIMS axis oriented as shown, the ring particles will impact the detector at an angle of about 40° from the instrument axis as will the asteroids.

Remembering that these units can all accept particles with angles (from their axes) of up to 60° (with somewhat lower effective area), the three cover a large fraction of the ecliptic plane and the important part of the northern hemisphere. The Earth-pointing IID(1) is primarily designed to measure the flux of "solar vicinity" particles as a function of solar distance. The IID(2) will measure interstellar particles while the IIMS will measure the number and mass analyzed asteroidal material, interplanetary particles, and Saturn ring particles. From Figures 1 and 2 it can be seen that interstellar particles can also be expected to impact the IIMS particularly in the latter part of the mission. Based on estimates of the mass of interstellar grains, the IIMS



is not expected to measure their composition but might make some determination of the larger particles.

The combined Impact Flash-Acoustic Detector and Sisyphus share a common telescope. As discussed above the IIMS pointing direction is optimized for the impact of asteroidal and Saturn ring particles. This pointing angle also yields a dark sky background (near the galactic north pole) for Sisyphus during the latter half of the MJS '77 missions when the solar intensity has been reduced appreciably. The pointing angle must be moved slightly from that of the IIMS to avoid the shadow of the scan platform passing through the Sisyphus  $2^{\circ}$  half angle fields of view. Early in the missions when the sun angle relative to the spacecraft Z axis is large, it does not appear feasible to avoid this problem at all times. However, the solar intensity is still high and the loss of data from very close particles can be tolerated. Figure 3 shows one possible pointing angle for Sisyphus and the Combined Impact Flash-Acoustic Detector in the same coordinate system as above. With the size of the anticipated stray light shields around the telescope, a  $45^{\circ}$  half angle acceptance cone can be expected for impacting particles. From the figure, it can be seen that asteroid and Saturn ring particles can be expected to impact the primary mirror for the sample JST and JSI missions.

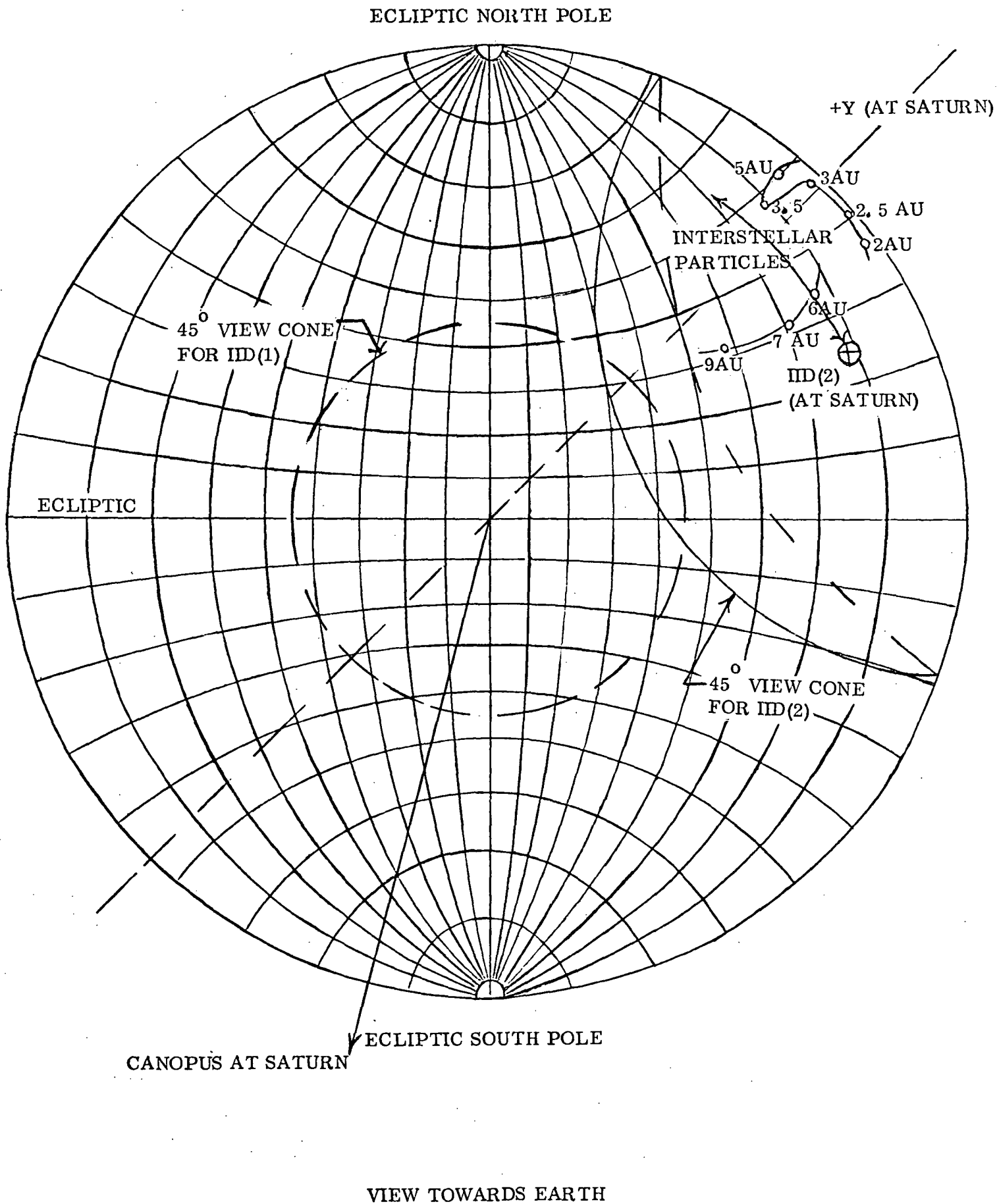


Figure 1

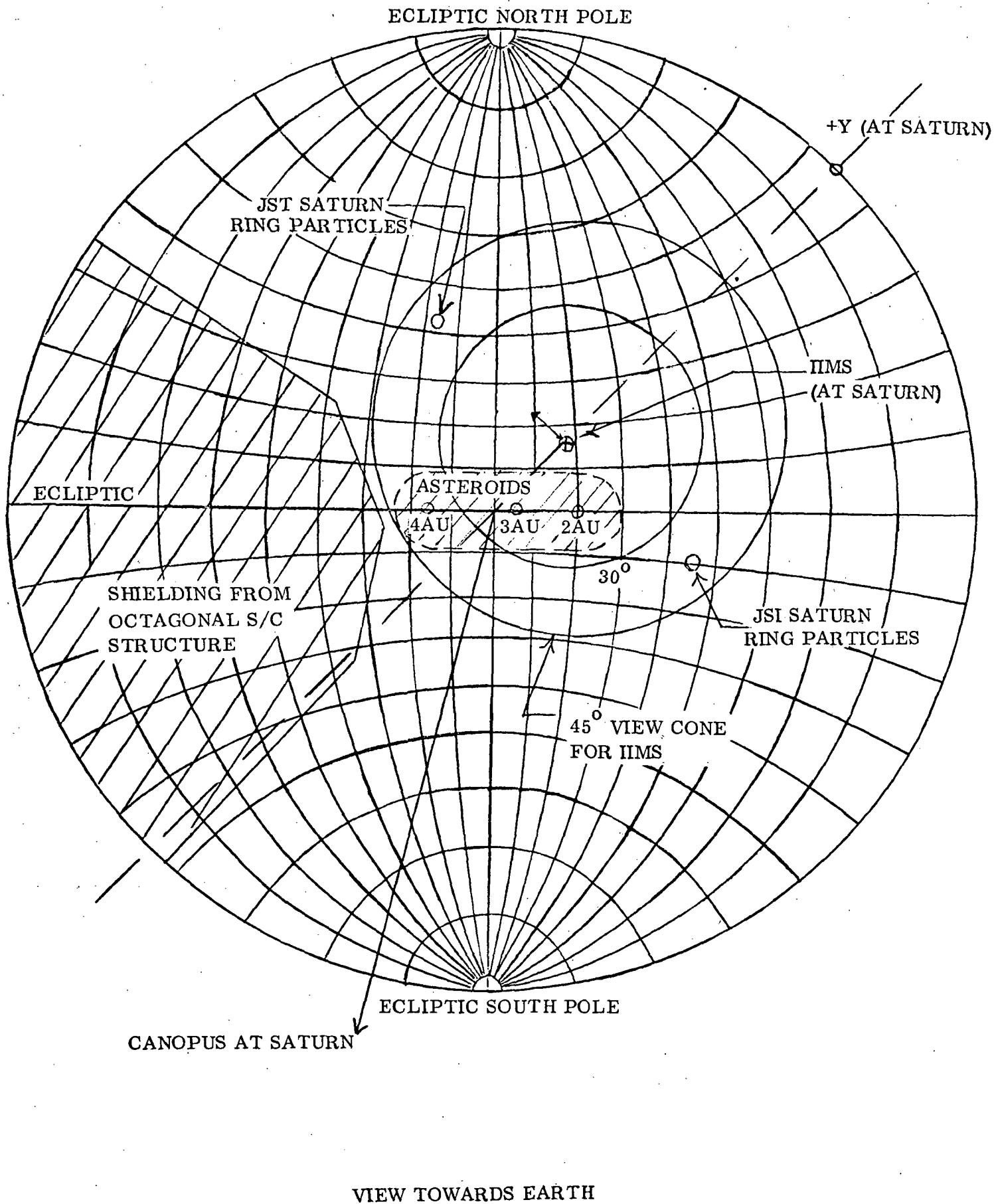
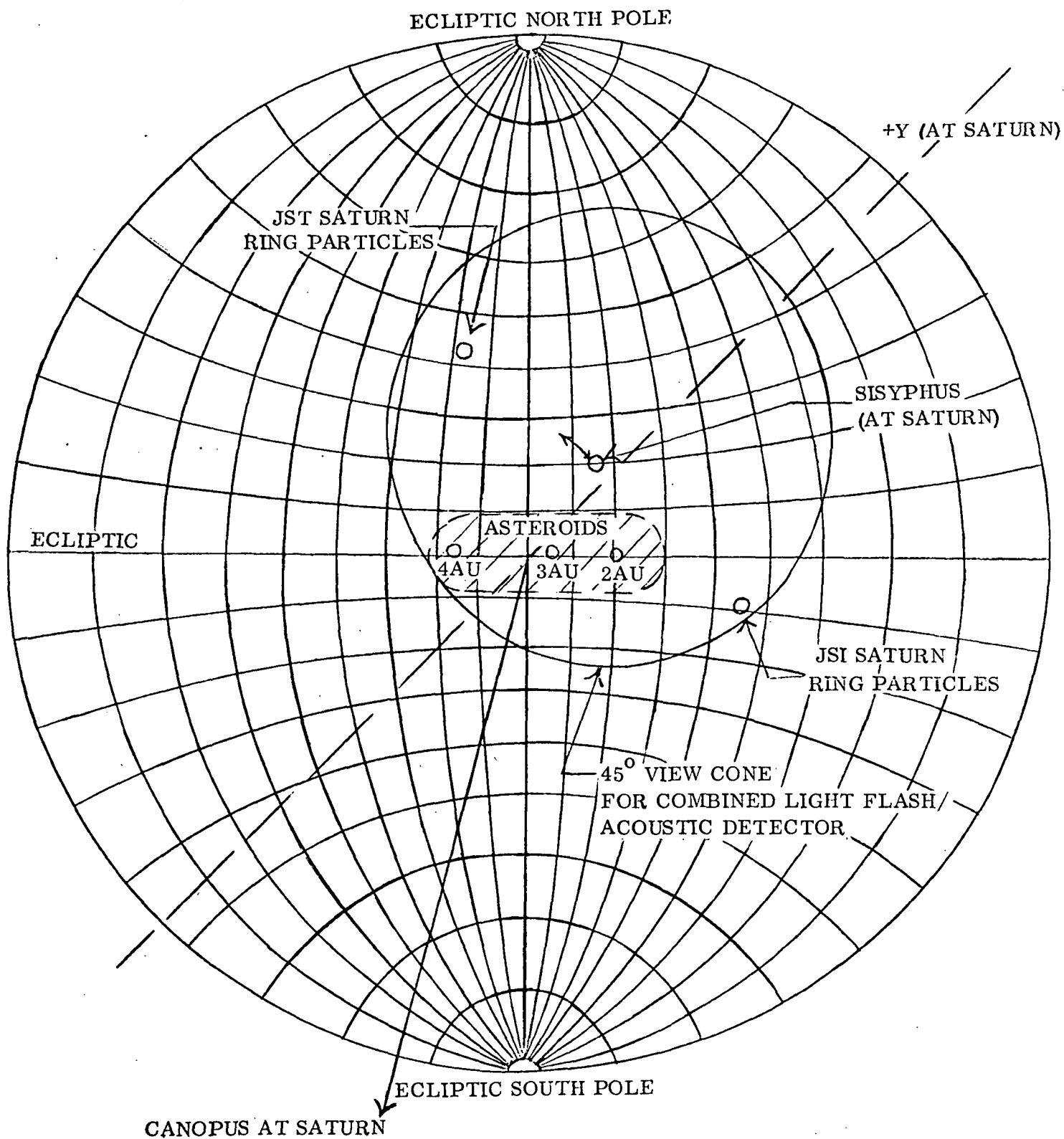


Figure 2



VIEW TOWARDS EARTH

Figure 3

## APPENDIX I

# CONFERENCE REPORT

JET PROPULSION LABORATORY

REPORT NO. 1

Page 1 of 3

SUBJECT Outer Planets Grand Tour Zodiacal Measurements Team Meeting #1

PROJECT OPGT CONTRACTOR Drexel University CONTRACT or

ACTION REQUIRED BY \_\_\_\_\_

TELECON Initiated by _____	Report Prepared by <u>G. L. Zomber</u>
CONFERENCE at <u>JPL</u>	Date Prepared <u>May 20, 1971</u>
Date of Occurrence <u>May 11, 1971</u>	Approved by Dr. R. K. Soberman
Participants	Distribution
R. Soberman, Team Leader J. Friichtenicht E. Gruen B. Lindblad A. Peterson R. Roosen J. Weinberg G. Zomber P. Theisinger - JPL	Participants Team Members T. H. Bird (10) - JPL R. L. Heacock - JPL M. Dubin - NASA/Headquarters D. G. Rea - JPL M. A. Mitz - NASA/Headquarters H. M. Schurmeier, JPL

## MAJOR TOPICS DISCUSSED

### 1. Experiment

- 1.1 For purposes of the zodiacal light portions of the combined experiment, it suffices if one of the telescopes is rotatable to permit viewing at  $90^{\circ}$  relative to the S/C roll axis. In conjunction with the TOPS vehicle yaw maneuvers this mobility would provide the two minimum zodiacal light scans, one in the ecliptic plane and one perpendicular to it. In this case, a filter wheel is needed to permit viewing at two polarizations, and two wavelengths are required  $\lambda \sim 4800\text{\AA}$  and  $\lambda \sim 6800\text{\AA}$ ; a bandwidth of  $200\text{\AA} - 500\text{\AA}$  is needed, the narrower bandwidth being preferred. The possibility of accomplishing the desired scans with a fixed orientation telescope through the use of vehicle maneuvers alone, will be pursued by Mr. Theisinger.
- 1.2 Mr. Theisinger will supply drawings of the spacecraft (S/C) to G. Zomber, to permit construction of a scale model.
- 1.3 The S/C 4.8 mhz clock is available for use in timing of logic in the experiment.
- 1.4 Counters and registers are also available; these form part of the control and conditioning logic (CCL).

- 1.5 Analog lines are available, but these require a 500 msec hold to permit multiplexing into the A-D converters. 5-bit and 10-bit A-D conversion is available.
- 1.6 E. Gruen, J. Friichtenicht and G. Zomber discussed ways of implementing the composition measurement to achieve a resolution of, at least, 50% in atomic mass number. Mr. Friichtenicht feels that a 10% to 20% resolution should be achievable with a 30 cm drift space and accelerating voltages not exceeding 200v. At 200v, the difference in arrival times of Si and Fe is about  $3.3 \mu \text{ sec}$ . An acceptance angle in excess of  $90^\circ$  is desired. Dr. Gruen and Mr. Friichtenicht also stated that charge amplifier sensing at the mirror is more sensitive than flash sensing.

The two particle composition experimenters agreed to come up with

- a. typical mechanical layout
  - b. calculation of grid size, shape, location, and voltages
  - c. expected mass number resolution (electronics not faster than  $1 \mu \text{ s}$ )
  - d. sampling channel number and block diagram
- 1.7 G. Zomber agreed to supply Dr. Lindblad with samples of the impact (mirror) surface materials as they are developed.

## 2. SSG Proposal

Dr. Soberman polled the team regarding the desirability to target our flight through Saturn's rings. The prime purpose is to attempt to obtain composition of particles making up the rings. All members of the team agreed that this was a highly desirable goal.

## 3. SSG Report

First rough draft plans and requirements for the SSG report were collected. These will be prepared and submitted by Dr. Soberman to meet the May 21st deadline.

4. Future Team Meetings

The following tentative schedule was agreed to:

June 13 - 14, 1971      Dudley Observatory, Albany, New York (in conjunction with  
the IAU Colloquium)

August 27, 1971

December 6, 1971

February, 1972

} Locations to be determined, but preferably in conjunction  
with other scientific meetings.



Minutes of the Meteoroid OPGT Team Meeting held at Amherst, Massachusetts

August 23 - 24, 1971

The prime purpose of this team meeting was to establish the requirements for the photometry portion of the meteoroid science package. Thus, attendance by team members not directly associated with the photometry was not encouraged. The attendees were: Drs. J. Weinberg, A. Peterson, and R. Roosen. In addition, Drs. G. Colombo and A. Cook sat in as observers.

Dr. Colombo made several suggestions for the team science definition. He pointed out the possibility of discovering new meteor streams. In the next issue of Icarus a paper by Colombo and Franklin predicts particles associated with the outer satellites of Jupiter produced by collisions. Preliminary calculations which Dr. Colombo has made indicate the possibility of a belt of stable orbits, approximately  $1/2$  AU across, located between the orbits of Jupiter and Saturn. Saturnian tidal evolution effects of Titan on Hyperion are negligible over  $4.5 \times 10^9$  years. However, the two are in commensurate orbits. Colombo and Franklin postulate a resisting medium which may very well be particulate in nature. As an overall statement, Dr. Colombo points out that the environments of the outer planets will most likely prove as interesting as the planets themselves in formulating the evolution of the solar system, and that the planetary environments as well as the planets are an important part of the basic scientific mission of the Grand Tour.

The three team members present formulated the following points with regard to the photometer measurements; these points constitute in their judgement a reasonable system:

1. The system should be capable of measurement in four colors with approximately a 100 Å bandpass. The four colors should be a) near-UV, b) blue, c) 5300 Å, and d) red. The detectors must be photomultiplier tubes and must use pulse counting techniques.
2. The system should be capable of measuring both, polarization and brightness (i. e., measure  $I_1$  and  $I_2$  separately).
3. The signal-to-noise ratio should allow measurement of brightness down to  $10 S_{10}$  visual units.
4. Data Recording - the system should have the capability of putting forth 10-bit words for  $I_1$  and  $I_2$  with a resolution of  $1 S_{10}$  visual unit.
5. The field-of-view of the system should be between four and six degrees.
6. Assuming a spin scan mode a) the instrument must be stray-light shielded, b) the main telemetry antenna must serve as a light shield, c) assuming a  $5^\circ$  field-of-view, there should be 24 steps,  $5^\circ$  apart, starting in the +Z direction and then going aft; there should be six calibration rotations.

7. An in-flight calibration source which is self-luminous should be mounted on the back of the shutter.
8. All four telescopes should be used for the measurement, stepped polarizers should allow scans in the two orthogonal polarization directions. This requires articulating the entire instrument.
9. With the assumptions given above, 30 rotations of the spacecraft are required.

The team members felt that there would be no real way to realize power saving by reducing the photometric portion of the combined experiment.

NOTE: The foregoing minutes and notations were relayed by telephone from Dr. R. Roosen to Dr. R. K. Soberman who prepared the final version to the best knowledge of the parties concerned.

### OPGT Meteoroid Team Minutes - Meeting #3

Meeting #3 of the OPGT Meteoroid Team was held at the Dudley Observatory in Albany, New York on June 14, 1971. In attendance were: Robert Soberman, Robert Roosen, Bertil-Anders Lindblad, Joseph Friichtenicht, Hugo Fechtig, Gerard Zomber, Alan Peterson and Jerry Weinberg of the Meteoroid Team. In addition Peter Theisinger of the Jet Propulsion Laboratory OPGT Project was present.

The first item on the agenda was the June 18 Proposal for NASA Headquarters funded studies. This was reviewed and revised for submission to NASA.

Questions concerning the possibility of other meteoroid scientists participating in the OPGT Meteoroid Team and SSG Meetings was discussed. In particular members of teams which might present competing proposals came up for discussion. It was decided that if representatives wished to participate in team meetings they would be permitted. SSG rulings would decide such representatives could attend SSG meetings. It was pointed out that minutes of all team meetings would be forwarded to anyone who responded to the Announcement of Flight Opportunity.

Duplication of meteoroid team experiment objectives with other SSG represented science team objectives was discussed. Of particular interest was the duplication with some of the objectives of the Photometry-Polarimetry team. It was agreed that preliminary discussions would be held between team members and team leaders to determine if combining of some experiment hardware was warranted.

A revised telescope/impact time-of-flight spectrometer configuration was presented to the team. The approach appears promising and additional work on this configuration was authorized.

It was decided that a meeting of team representatives on the subject of combined electronics should be held as soon as possible. R. K. Soberman was to organize this meeting.

#### OPGT Meteoroid Team Minutes - Meeting #4

The fourth OPGT Meteoroid Team Meeting was held at the NASA Goddard Space Flight Center in Greenbelt, Maryland on November 2 and 3, 1971. Team members in attendance were Robert Soberman, Robert Roosen, Bertil-Anders Lindblad, and Joseph Friichtenicht. Eberhardt Gruen represented Hugo Fechtig. To facilitate the discussion of electronic instrumentation, several electronic engineers who were familiar with the sensors were invited to participate. These were Mr. Goran Arinder of the Lund Observatory, Mr. G. M. Crook of TRW, Mr. Ed. Howard of General Electric and Mr. Peter Gammelin of the Max Planck Institut. Mr. Peter Theisinger of the Jet Propulsion Laboratory represented the OPGT Project. Mr. Otto Berg of NASA Goddard was present as an invited observer.

The principal topic of discussion was the electronic integration of the Combined Zodiacal Experiment. The discussions resulted in the following conclusions.

1. Only one telescope will be instrumented for impact detection. All four telescopes will be instrumented for Sisypus and sky brightness measurements.
2. Detection of ionization by the time of flight portion of the instrument will trigger collection of microphone, time of flight and light flash data.
3. The time of flight, microphone, Sisypus and sky brightness portions of the experiment will be independently powered.
4. It is desirable for the instrument power supply to be located in the Control and Conditioning Logic (CCL).

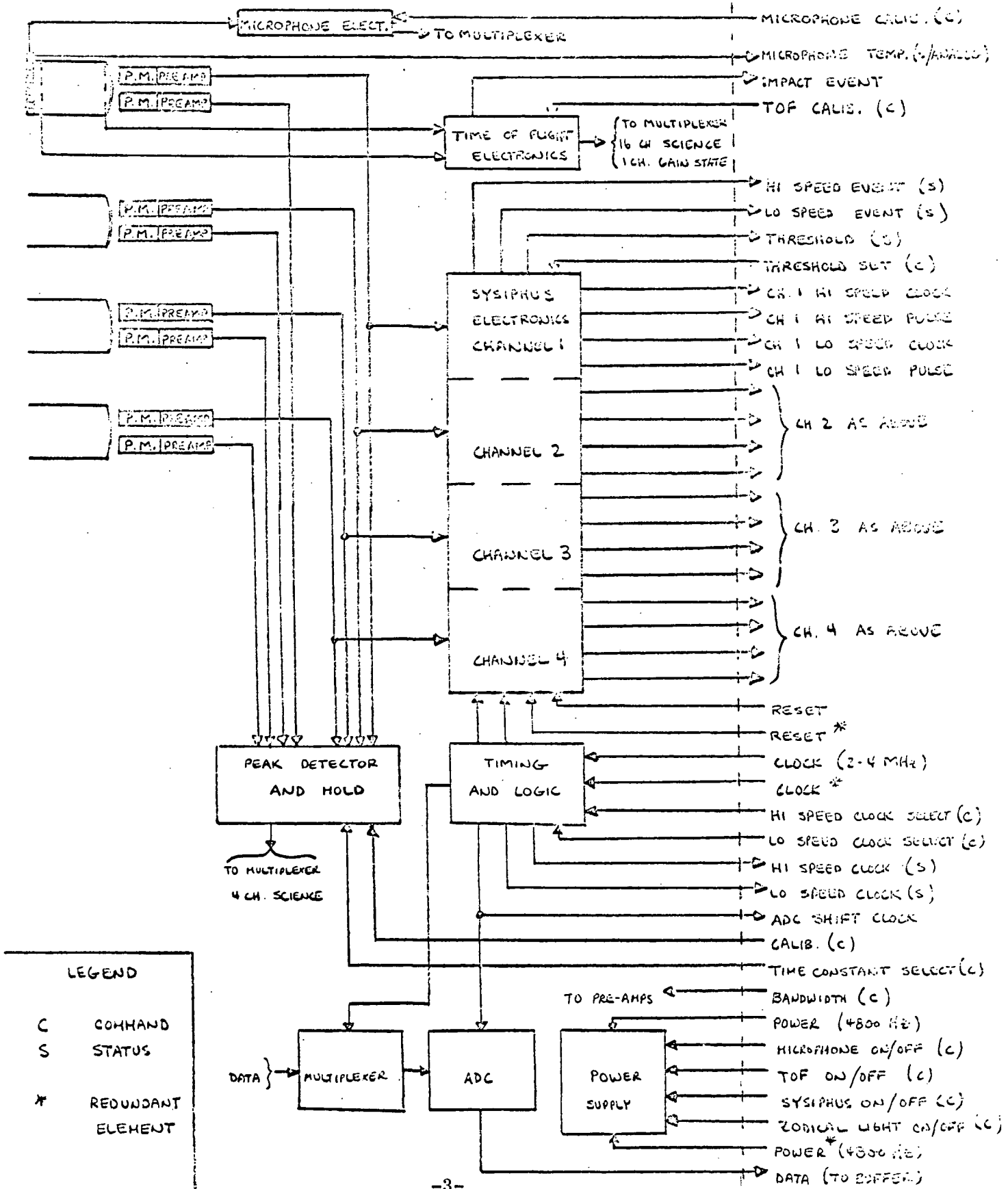
As a result of these discussions, a Combined Zodiacal Experiment block diagram was prepared, and is attached. In addition, the requirement was levied that the experiment be gimballed about one axis perpendicular to the S/C roll axis to allow for a sky brightness mapping.

At the conclusion of the meeting the following action items were levied against the team.

1. Independent weight and power estimates from the various elements of the experiment.
2. Combined weight and power estimates.
3. Estimate of highest high voltage required.
4. Sky brightness
  - a. Can sky brightness experiment live with 45° dichroic filter.

- b. Lowest weight polarization scheme with rough optical drawing.
- c. Calibration requirements.
- d. Assuming one sky brightness telescope, estimate filters required, special constraints, etc.

TITLE COMBINED ZODICAL EXPERIMENT BLOCK DIAGRAM



- LEGEND
- |   |                      |
|---|----------------------|
| C | COMMAND              |
| S | STATUS               |
| X | REDUNDANT<br>ELEMENT |

## OPM Meteoroid Team Minutes - Meeting #5

The fifth meeting of the OPM Meteoroid Team was held at Drexel University in Philadelphia, Pennsylvania on January 26 and 27, 1972. In attendance were Robert Soberman, Alan Peterson, Joe Friichtenicht, Gerard Zomber, Jerry Weinberg, Bertil-Anders Lindblad and Eberhardt Gruen representing Hugo Fechtig. Maurice Dubin of NASA Headquarters was present as an invited observer.

The first item on the agenda was the discussion of the demise of the Grand Tour Missions. Dr. Soberman briefed the attendees on the alternatives for the Outer Planets Missions. In particular, the Mariner/Jupiter/Saturn '77 Missions were discussed at length. Material presented to the Science Steering Group on January 24 and 25 was presented to the attendees of the team meeting and are appended to these minutes. Changes in scientific objectives for the Meteoroid Team related to this new mission set were discussed. The primary change was the new emphasis upon the investigation of Saturn's rings. It was decided that the team should continue studies on the combined zodiacal experiment. Apart from the completion of those studies already underway related to radiation hardening and long life, future efforts would be directed to making maximum use of existing hardware designs for the impact time of flight spectrometer, Sisyphus, microphone and photopolarimetry.

The team decided that it would continue pressing for the combined instrument, but would also continue developing other alternatives. It was decided that a separate encounter mode would now be required for the meteoroid experiment to allow for the intensive studies of Saturn's rings. The uncertainties to be encountered at Saturn dictate that instrument characteristics, rather than anticipated ring phenomena would set the telemetry rate. A maximum data rate of 2 kilobits per second would be requested. The experiment should go into this encounter mode at approximately six Saturn radii and continue until to 6 radii outbound. If storage capabilities do not permit this maximum data rate for that period, some compromise could be made. It is anticipated that maximum data would be obtained just before and just after encounter with the visible rings. In the visible rings, it might be anticipated that all sensors would go into a current rather than discrete event mode, but that current levels would continue to measure the number of particles encountered.

The importance of the two color photopolarimetry was pointed out with respect to the measurements of Saturn's rings, particularly if the rings have very sharp boundaries and only remote data would be obtained. The importance of all of the individual measurements of the combined zodiacal experiment to the study of Saturn's rings was reviewed.

The two sample trajectories for Mariner/Jupiter/Saturn '77 were reviewed. The team found these to be ideal for the purposes of particulate measurement at Saturn and prior to the Saturn encounter.

The team decided that the detailed measurements in the asteroid belt should receive new emphasis as part of MJS '77 and that these objectives should receive equal weight with the detailed measurements at Jupiter.

The OPGT Meteoroid Team Report was reviewed for submission to meet the February 1 deadline of the OPM project.

A major item of discussion was ways to reduce instrument and science support costs for a reduced budget MJS '77 mission set.

As an action item, all of the team members were to review existing knowledge and models of the Saturn ring system and try to develop new models for use by the Meteoroid Team. Further attempts would be made to show how specific measurements could distinguish between models or eliminate existing hypothetical models.

It was mentioned that NASA is funding an earth based study of a star occultation by Saturn's rings expected in 1972. It was pointed out that any model of the rings which has kilometer boulders would predict starlight modulation with total or partial obscuration for tens to hundreds of milliseconds. This would not be measurable by integration techniques such as photography but should be detectable by photomultiplier measurements. It is thus strongly recommended that such measurements be carried out during the occultation to set an upper limit on the size of the ring constituents.

Future team meetings and actions will await decisions by NASA and the OPM Project on future direction. It is anticipated that such information should be available after the March SSG Meeting.



## OPM Particulate Science Team Minutes - Meeting #6

The sixth meeting of the OPM Particulate Science Team (formerly Meteoroid Science Team) was held at the General Electric Offices on West Century Boulevard in Los Angeles on July 26 and 27, 1972. Team members in attendance included J. Friichtenicht, B. A. Lindblad, A. Peterson, R. Roosen, R. Soberman, J. Weinberg and G. Zomber. In addition, E. Grün of the Max Planck Institut für Kernphysik was present representing H. Fechtig. C. Lillie and L. Dorman of the Laboratory for Astronomy and Space Physics of the University of Colorado were also present by invitation.

The first item was a discussion of team membership. It was decided that for future activities in the OPM Program, the team membership should be changed. This would be reflected in the proposal for the next phase. Added to the team membership were Drs. Grün, Lillie and House of Drexel University. Mr. Zomber, who would continue in the role of Principal Engineer and Deputy Program Manager would no longer be listed as a team member. The team also voted to list the names of Dr. R. Giese of the Bochum University, Dr. R. McCrosky and Dr. A. Cook both of Smithsonian Astrophysical Observatory as team consultants. It was felt that that the analytical and theoretical expertise of these latter three colleagues would be extremely valuable during the data analysis phase of Outer Planets Missions Program. It was decided that they should be listed as consultants for the present and be considered for team membership in the late portion of the implementation phase should the team's proposal be selected for the Mariner/Jupiter/Saturn '77 Missions.

The team then reviewed the details of the sky brightness measurements. Dr. Lillie and Mr. Dorman presented their design for the photopolarimeter portion of the combined instrumentation. It was decided that should the team proposal be selected for implementation, this portion of the hardware would be built at the University of Colorado.

The team also voted to propose using the Data Center at the University of Colorado for data receipt and preliminary reduction. It was generally agreed that this was one of the best facilities of its kind in the world and its use would considerably shorten the time period from data acquisition through preliminary and final analysis.

Dr. Grün and Mr. Friichtenicht then presented the results of their combined efforts on the microparticle impact ionization and composition analysis. They showed why it was necessary to utilize three subunits to meet all of the science objectives. As part of this discussion, pointing for all portions of the proposed instrumentation came under consideration. A report on pointing and acceptance angles for the various portions of the instrumentation was reviewed.

Finally the team reviewed details of the proposal to be submitted to NASA Headquarters for the Mariner/Jupiter/Saturn '77 Missions. Plans for the final team report to Headquarters on NASA funded activities were also discussed. It was decided that the team members would make their submissions to Dr. Soberman who would be responsible for preparing and submitting the final report.

All present then expressed the hope that the team would reconvene in December of 1972 or early 1973 after having been selected for the Particulate Science Investigation on the Mariner/Jupiter/Saturn '77 Missions.